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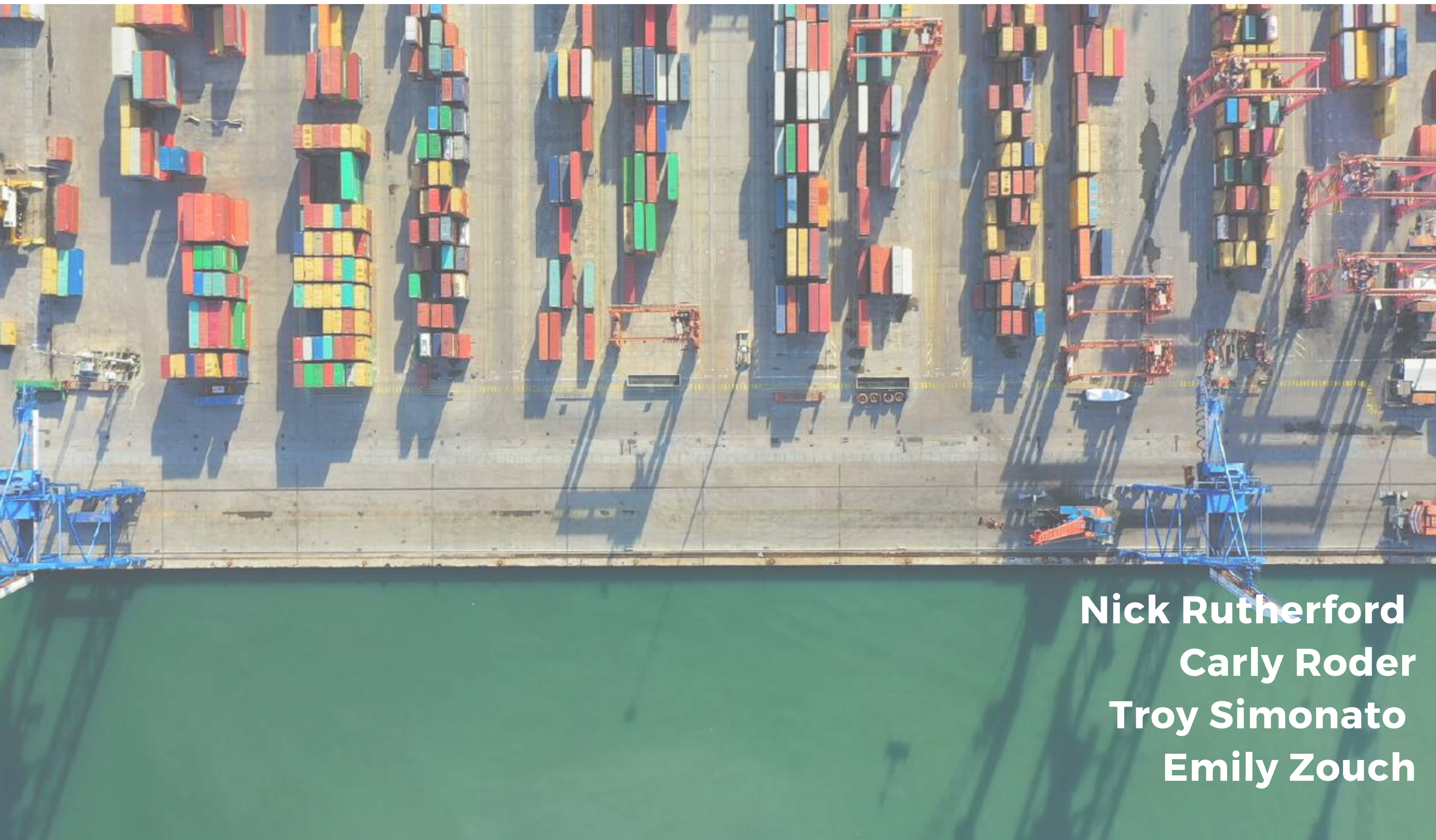
UNINTENDED CONSEQUENCES OF LARGE DEVELOPMENT PROJECTS IN MARINE AND COASTAL ENVIRONMENTS

OCTOBER 2021



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This report is the work of post graduate students from Macquarie University who have undertaken a unit ENVS8544 Sustainability Consultancy Work Practice as part of a Master degree. It was written for the United Nations Environmental Program (UNEP)/Nairobi Convention.

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Abbreviation List

AOI	Area of Interest
AV	Simple Averaging
AVW	Weighted Averaging
CHL1	Chlorophyll
COP	Conference of Parties
EBM	Ecosystem Based Management
GIS	Geographic Information System
GSM	Global System Mobile
KDPAR	Wave Length of Light/Photosynthetically Available Radiation
KPA	Kenyan Port Authority
LULC	Land Use Land Change
MSP	Marine Spatial Planning
SDG	Sustainable Development Goal
SEA	Strategic Environmental Assessments
STS	Ship to Shore
TEU	Twenty-foot Equivalent Units
TSM	Total Suspended Matter
UNEP	United Nations Environmental Program
WIO	Western Indian Ocean
WIOSAP	Western Indian Ocean Strategic Action Plan

Executive Summary

Development in the Western Indian Ocean (WIO) has increased significantly in the past two decades, and is likely to continue to grow rapidly in the coming years. Growing consumer demand, an increasingly competitive shipping market, and more freely available credit to fund expansion has meant that infrastructure developments in the region have been growing at an unprecedented rate. Alongside economic benefits, there are also environmental and social concerns that have arisen due to this expansion. Agreed upon in 2013, *Agenda 2063* is the overarching blueprint designed to guide the region - as well as wider Africa - towards collective prosperity and was created with the goal to "transform Africa into the global powerhouse of the future". Recognising the importance of sustainable development alongside economic growth for its member states, *Agenda 2063* links it's own goals to that of *United Nations Sustainable Development Goals* (SDGs), created in 2015.

Regionally, the *Nairobi Convention* and its member states have implemented several projects to manage this progress towards sustainable development. Specifically, the *Conference of Parties* (COP) to the *Nairobi Convention* aim to maintain and protect rivers, coasts and oceans in the WIO. One such project is the *Western Indian Ocean Strategic Action Plan*, or WIOSAP. Working alongside the United Nations Environmental Program (UNEP) as its implementing agency, the ten participating WIOSAP countries (Comoros, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Somalia, South Africa, Tanzania, and France as a non-project beneficiary) aim to minimise environmental stresses as a result of land based activities in the period, with the project slated to run until 2021.

This report has been undertaken with the aid of UNEP to examine some of the negative environmental impacts that have been seen in the region, specifically focussing on port developments. Mombasa Port has been used as a case study to examine what some of these impacts are; however, many of the findings from the analysis undertaken could be applied more broadly to port developments throughout the region. It examines the drivers of this growth in the region and what projections will be in the coming two decades. Water quality and land use and land changes are also analysed over a twenty year period, coinciding with the modernisation of the Mombasa Port terminal modernisation project.

Given Mombasa Port's significance in the region, being the second largest port in the WIO, it provides valuable insight into issues which are relevant for other member states of the *Nairobi Convention*. The desired objective of this report is that it will showcase the environmental degradation that can take place as a result of port development and offer summary solutions to mitigate this in future. Similarly, it serves as a precautionary tale to port development at Lamu that environmental issues need to be suitably addressed as the recent development looks to expand significantly in the coming years.

From the analysis undertaken at Mombasa Port, there are three key findings:

- The modernisation project at Mombasa Port - inclusive of dredging, channel widening, and terminal construction - likely increased Chlorophyll and KDPAR levels over the period.
- Land use change around the port area has been driven almost exclusively driven by human factors, with built up areas and agricultural lands increasing at the expense of sparse forests, forests and bare soils.
- Ecosystems at the intersection of human land use and marine environments have also suffered as mangrove cover has decreased and water body surface area has increased over the twenty year period.

Water quality was assessed using open-source online remote sensing data to provide a broad overview of trends and changes in water quality over time. Three parameters were used, including chlorophyll, total suspended matter (TSM) and turbidity. Results indicate that chlorophyll levels peaked during 2007, which aligns with the start of construction for the new container terminal modernisation project and sand harvesting nearby Shelly Beach. Both chlorophyll and turbidity levels show a slight increasing trend throughout the 2010's, which coincides with increasing development at Mombasa Port. It is therefore highly likely that this trend can be attributed to the port and associated coastal development. It should be noted that data had significant gaps and is likely to have noise or data inaccuracies as a result of the low-resolution data. Further work in this area is recommended.

Analysis of land use land change (LULC) was undertaken with reference to the Mombasa Port region. The analysis used files provided by UNEP and aimed to determine the changes to built up area, bare soils, sparse forest, forested land, agricultural land, water bodies and mangroves. Results indicate that as built up and agriculture land increase, while there are declines in mangroves, bare soils, sparse forests and forests. Bare soils, sparse forests and forests also seem to share a close relationship change. This is likely a result of their natural progression from each other. Additionally, these changes are dictated by population increases and anthropogenic systems expanding within the study area. Finally, mangroves show a steady rate of reduction, threatening natural ecosystem balance and potentially harming economic interests in the area.

Given the dependence of many people in the region on marine ecosystems on for their livelihoods, environmental concerns as a result of land based development is not simply limited to ecosystems; it is very much a societal problem too. With significant growth projected in the region, port developments will continue to expand. As they expand, every effort should be taken to minimise the environmental and social fallout of increased infrastructural expansion. Consultation with all affected stakeholders should be undertaken *prior* to planned development to better understand any negative impacts. Similarly, it is advised that rigorous environmental standards be upheld, with impact assessments undertaken at every relevant stage of planning.

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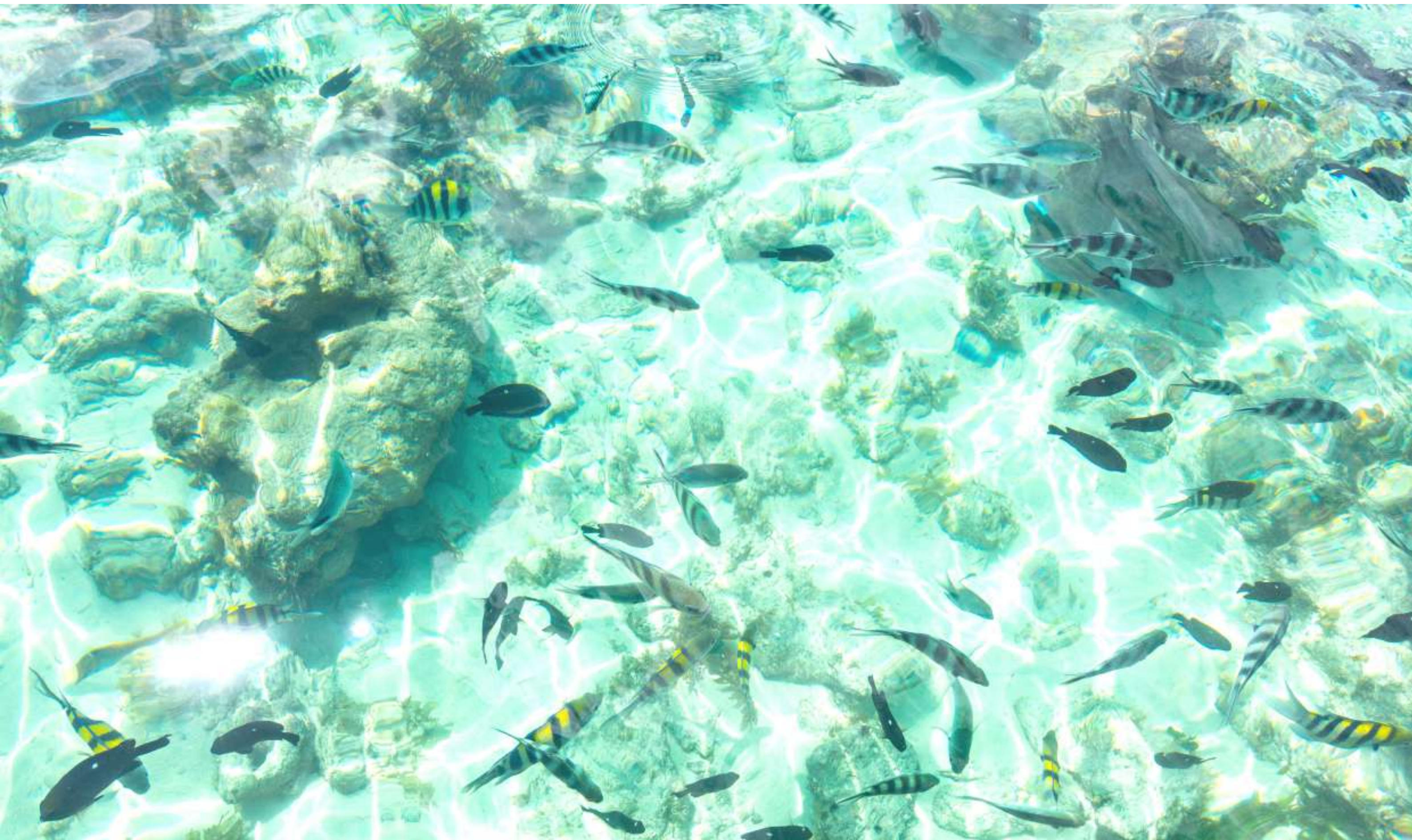
1.

INTRODUCTION



1.1 Project Background

The WIO region of Africa is experiencing large-scale change within its marine environment, including port and harbour development. These land-based activities are sprawling into the marine environment, often causing degradation of coastal ecosystems through interrupting flow regimes, reduction in water quality and habitat destruction. This project forms part of the larger Western Indian Ocean Strategic Action Plan (WIOSAP), which aims to reduce the impacts of these land-based activities and sustainably manage critical coastal and marine ecosystems. The WIOSAP project recognises the need to protect the environmental assets of the WIO coastal regions and provide essential goods and services as part of the region's commitment to the *Nairobi Convention* and UN's *2030 Sustainable Development Goals*.

The *Agenda 2063* masterplan for Africa focuses on frameworks that will drive African nations towards becoming global powerhouses through sustainable and inclusive development. The WIO region has a gross marine product of US $20.8 billion dollars (Maritime Executive, 2021); this showcases the economic value of its delicate ecosystem and highlights the need to focus on sustainable development within marine environments. Through collaboration with foreign nations and utilising tools such as marine spatial planning (MSP), strategic environmental assessments (SEA) and ecosystem-based management (EBM), port developments can continue to meet both economic and environmental goals.

Much of the WIO region’s livelihood is dependent on ecosystem services provided by the area's vulnerable and unique coastal ecosystems (UNEP, 2015). The WIO region currently supports over 60 million people and is experiencing rapid rates of population growth and urbanisation, including coastal development such as ports (UNEP, 2015; UNEP, 2016).

1.2 Project Objectives

This report examines the change in urban development in the WIO region using Mombasa Port as a case study. Furthermore, it establishes a link between ecological assets and port development in Mombasa.

The objectives of this project are to analyse the following:

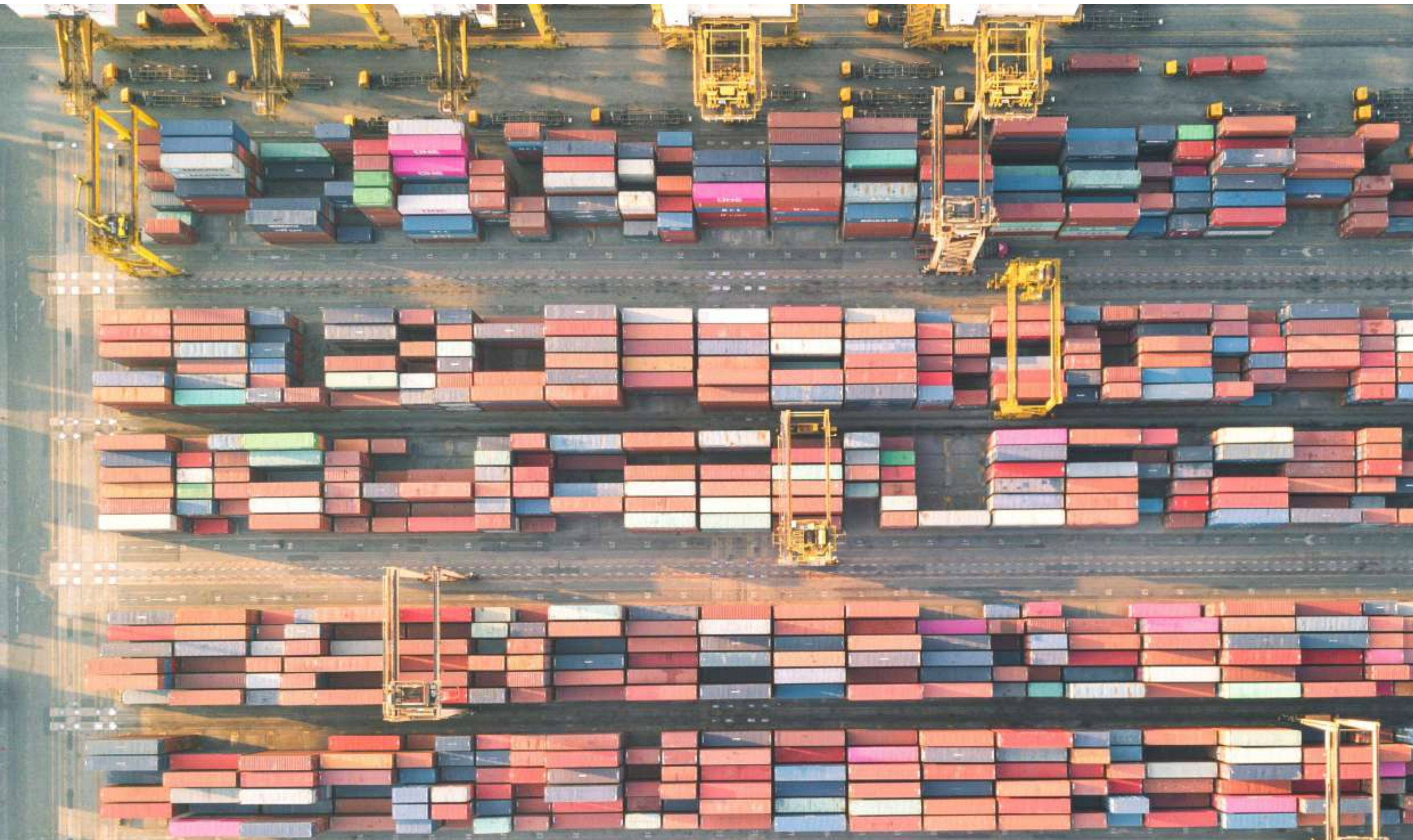
1. The rate of change in urban development relating to larger ports in the WIO.

2. Mombasa Port development in relation to urban expansion.

3. The implications of port development on ecological assets within the coastal ecosystem, with a focus on mangrove cover and water quality.

2.

COASTAL DEVELOPMENT IN WESTERN INDIAN OCEAN



2.1 Major Coastal Developments in WIO

The WIO region comprises of five countries on the east coast of Africa, as well as six islands within the Indian Ocean. These coastal nations act as the gateway to many landlocked nations in Africa, and require infrastructure to permit transport of goods and services within and between countries and the rest of the world. Figure 2.1 below shows the existing coastal developments, or ports within the WIO region, and the development corridors between coastal regions and inland Africa.

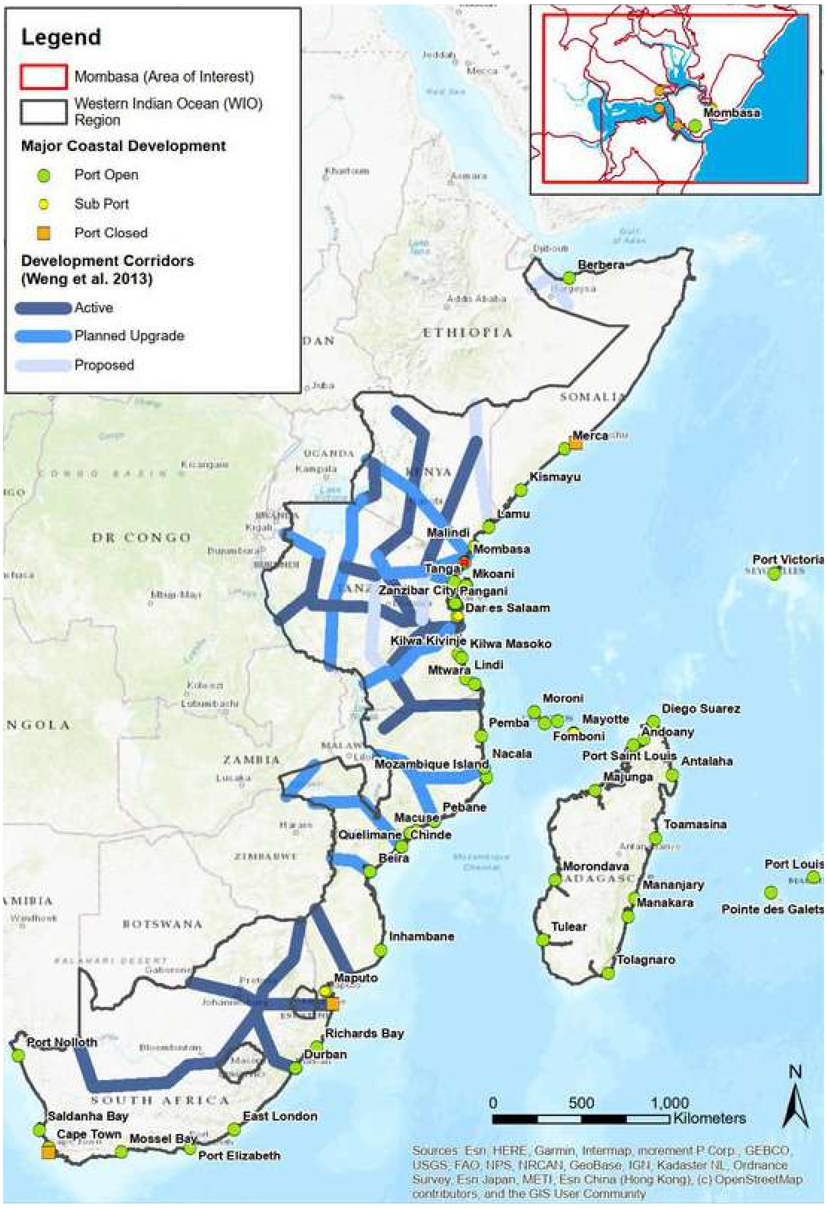


Figure 2.1: Coastal development and associated corridors within the WIO region. Some corridors listed as 'Planned Upgrade' have since been implemented or are in the process of implementation.

Whilst Africa has traditionally been dependent on agriculture, it has been experiencing rapid rates of growth over the past decade, largely driven by increased mining activity (Weng et al., 2013; UNEP, 2015). Extracted minerals and resources are often exported, requiring robust infrastructure to be transported to ports (Weng et al., 2013). This infrastructure is driving growth as it opens up export options for the agricultural industry, which was previously constrained by lack of market access (Weng et al., 2013).

WIO nations are strategizing growth planning; this has resulted in increased port capacity. However, it has recently been identified that container demand is expected to exceed current capacity by 2030 (World Bank, 2018). Future planning will need to consider which ports are best suited to be regional hubs. Furthermore, improved efficiency of operations is required in all WIO region ports (World Bank, 2018).

Governments are prioritising spend on port infrastructure, with different countries competing for their port to be a regional hub for Africa. For example, both Kenyan and Tanzanian governments have allocated $138M and $1.3B respectively to port and infrastructure projects in their 2021-22 budgets to target inland markets of landlocked nations (Maritime Executive, 2021).

It is highly likely in the short and long term that port development will accelerate in the region. Increased demand for consumer goods, regional competition for shipping contracts, and increased credit opportunities from China and Japan have fuelled this growth in port infrastructure. Ports will need to grow in capacity to accommodate for increased demand.

Table 2.1 outlines the extent of the major ports in the region that are party to the *Nairobi Conference* and the upcoming developments slated for the next decade. With the exception of ports at Moroni and Nacala, every other port in the region has planned development in the form of dredging, channel widening/deepening, terminal expansion/creation, berth creation and other associated infrastructure considerations, such as rail and road development. Each of these brings millions of dollars into local economies, however, are major environmental considerations for the surrounding ecosystems.

While it’s widely acknowledged that environmental considerations should be managed by private operators, and not the port authorities themselves, there are still a number of ports whose environmental principles are upheld by the port authority itself or a public authority. Furthermore there are several countries such as Comoros, Mozambique and Somalia, who are recognised as having inadequate environmental principles, making infrastructure development environmentally and socially problematic (World Bank, 2018).

Table 2.1: Overview of Major Ports in the WIO and Upcoming Developments planned in 2016 (Tonnage figures from World Bank, 2018).

Port	Country	Tonnage (2016)	Overview	Upcoming Projects
Port of Berbera	Somalia	2,993	Strategically located in the north-western region of Somalia, servicing the Ethiopian corridor.	Additional warehouses, silos and dryports including 600m quayside equipped with seven more STS gantry cranes.
Mombasa Port	Kenya	27,364	Kenya's primary port, and the main gateway and exit port for cargo belonging to a large landlocked hinterland.	Widening of entrance channel bends, dredging of turning basin, creation of a freeport area.
Lamu Port	Kenya	n/a	Kenya's new greenfield port project located north of Kenya.	Construction of 29 additional berths (to complement current 3).
Dar es Salaam Port	Tanzania	13,658	Located on the coast of the Indian Ocean; handling about 95 percent of Tanzania's international trade.	Funding allocated for the improvement of berth numbers one to five, completion of the construction of a RO/RO berth.
Port of Zanzibar	Tanzania	1,170	located on the western part of Zanzibar and acts as the island's main port.	Agreement for funding of multi-terminal port at Unguja's Mangapwani suburb.
Mornoni Port	Comoros	291	Small regional port located on the western side of the main island of Comoros.	No planned infrastructure development.
Port of Toamasina	Madagascar	5,921	Located on the eastern edge of the island, it represents approximately 35 per cent of total employment in Toamasina.	Production of wave absorbtion blocks, extension of break water, construction and deepening of container berths.
Port of Mahajanga	Madagascar	350	Second port in the country and focuses on local traffic on the west coast of Madagascar.	Establishment of an offshore loading and unloading system for bulk cargo using tugs and large barges.
Port Louis	Mauritius	7,273	Largest port of Mauritius, handling approximately 99 percent of the total trade volume.	Proposed development of an island container terminal with a capacity of 1.5 Million TEUs.
Port of Nacala	Mozambique	8,446	It is the largest natural deepwater port on the eastern coast of Africa.	No planned infrastructure development.
Beira Port	Mozambique	9,496	Regional port located at the mount of the Pungue River.	Dredging of the trailing suction vessel channel and the harbor basin.
Port of Maputo	Mozambique	14,519	Regional port located in the southern region of Mozambique.	Expansion of the coal and container terminals planned over the coming decade.
Port of Durban	South Africa	66,829	The port of Durban is a key gateway port and transshipment hub, located along the east coast of South Africa.	New terminal planned, deepening of the Maydon Wharf channel, along with the infill of Pier 1/2 to increase capacity.
Port of East London	South Africa	2,076	South Africa's only river port, and consists of a RO/RO terminal, South Africa's largest grain silos.	Refurbishment of the port's dry dock, reconstruction of Quay 3, the introduction of a landing jetty.

2.2 Port Development Impacts On Coastal & Marine Ecosystems

While well-functioning ports play an integral part in economic development for the region and surrounding hinterland, port activities have significant adverse impacts on the environment. Port development relies extensively on fossil fuels and large energy consumption, significantly contributing to climate change. Emissions of carbon dioxide, nitrous oxides, sulfuric oxides and particulate matter are all concerns for the surrounding ecosystems and people living and working near ports. However, within the scope of this report, we are focused on the negative impact's ports have on surrounding environments, particularly through water pollution and land-use changes.

Spills, Operational Discharges of Oil and Hazardous Cargo

Discharge of hazardous spills and noxious substances into the waters surrounding ports can have a large impact on ecosystems (Magnusson et al. 2018). Various mechanisms exist for pollutants to enter waterways, including through bilge water, from the lubrication of propeller shaft bearings and the illegal cleaning of tanks (Miola et al. 2009). Bunkering operations, which is the supply of fuel for ship use, engender oil spill risk, particularly when poor management and regulations are in place (Dinewoodie et al. 2012). Hazardous cargo poses another threat, such as accidents or leaching of coal, petrochemicals, ammonia and acidic substances, which can occur through stages of cleaning, repairs and inadequate decontamination (OECD, 2011).

The environmental impact and recovery of such discharges rely on whether the pollutant is transported, in particular, when oil spills are carried along currents to surrounding ecosystems (Afenyo et al. 2016). Various adverse impacts have been found for the ingestion or contact with petrochemical substances in coastal ecosystems (Mendelssohn et al., 2010) and specific species such as sea birds (Neuparth et al. 2012) and fish (Rogowska & Namieśnik, 2010). Mangrove ecosystems have also been shown to be vulnerable to chronic impacts from the cumulation of petrochemical and carcinogenic compounds from shipping activities, particularly as a source of food and habitat for organisms and surrounding communities (Garcia & Martins, 2021).

Sewage and wastewater

Sewage, sludge and ship wastewater can enter the marine system through improper procedures in waste management, resulting in organic, biological, chemical and toxic pollutants impacting the surrounding environment (OECD, 2011, Lindgren et al., 2016). The introduction of increased nitrate levels in the marine system can increase phytoplankton growth resulting in algal blooms and eutrophication of aquatic environments. The impacts for wastewater pollution are varied, from altering ecosystem composition due to eutrophication, contaminating species like shellfish that are consumed for food, resulting in a risk for public health, as well as adversely impacting tourism industries (Lindgren et al., 2016).

Marine litter

Solid wastes from port activities are varied, including waste from food preparation, ship operation and from cargo-related activities such as packing materials, and as such may include organic, biological, chemical, plastic and toxic pollutants (OECD, 2011). The transportation of marine litter over vast distances in the ocean has resulted in it contaminating ecosystems far beyond the source of input.

The entanglement and ingestion of litter directly impacts organisms (Donnelly-Greenan et al. 2019). Other negative effects include smothering and burial of seabeds, habitat disturbances, transferring invasive species as well as facilitating the leaching of toxic substances into marine environments (UNEP, 2005). Furthermore, the negative impacts of microplastics on marine systems is still unfolding, with their impacts on small organisms such as invertebrates likely similar to macroplastic ingestion in larger animals (Wright et al., 2013).

Antifouling

Materials submerged in water are prone to fouling by marine organisms. For ship hulls, this increased friction and drag when moving through water increases the fuel consumption of the vessel. Antifouling is required to improve the speed and efficiency of a ship, as well as reduce the transportation of invasive aquatic species across regions (OECD, 2011). Widely used antifouling paints are usually toxic and gradually leach harmful biocides into the surrounding water. Historically, Tributyltin was extensively used until its ban in January 2008 by the International Maritime Organisation (2021) when overwhelming evidence demonstrated the biocide’s negative impact on non-target organisms, such as shell malformation of oysters and imposex of gastropods (Dafforn et al. 2011).

With the shift away from Tributyltin, copper antifouling paints have become the predominant biocide used due to it high toxicity for most marine organisms and affordability, although it too has become restricted by some countries due to toxic leaching and its persistent long lifetime in the environment (Dafforn et at. 2011). Booster biocides are used in conjunction with copper paints to address algal groups, which may be resistant to Copper, with multiple boosters used worldwide that negatively affect photosynthetic organisms (Arrhenius et al. 2006, Dafforn et al. 2011).

Ballast Water

Ships use ballast water to control the centre of gravity in relation to cargo carried for stability and manoeuvrability, therefore, the exchange of ballast seawater from one region to another is required when moving cargo between ports (OECD, 2011). Seawater carried inevitably contains many marine organisms which can be transported around the world, resulting in invasive non-indigenous species of organisms being dispersed across biogeographic barriers that would naturally prevent their spread. The transfer of non-indigenous species into new, potentially sensitive environments has been extensively studied (David et al. 2007, Al-Yamani et al. 2015, Cabrini et al. 2019).

Land Use Change

Port development requires alterations to large areas on land and changes to water systems. The spatial imprint extends from immediate port facilities to infrastructure including roads, rail, warehouses and industrial areas but also promotes increased city and urban development adjacent to the port, which benefits from the transport nexus. Port cities have a profound influence on land use patterns, with higher development intensity in early stages generally closer to the ocean; as development moves into later stages, building expands into surrounding environments (Yan et al., 2021).

This can result in habitat loss of surrounding ecosystems, such as estuaries, wetlands, coral reefs, as well as adverse effects on biodiversity, migratory species and endangered species in general (OECD, 2011). Furthermore, shifts in land use can result in the resettlement and loss of livelihoods for vulnerable communities around port development (Delphine et al., 2019).

Land use alterations during coastal development is particularly significant for mangrove cover around the world. Mangroves support a variety of valuable ecosystem services, including coastal protection, climate change mitigation, biodiversity maintenance, fishery enhancement and tourism (Brander et al., 2012, Rahman et al., 2018). These critical ecological assets are declining due to global and local pressures (Worthington et al., 2020). Human pressures have also exacerbated sea level and macroclimate drivers (Maina et al., 2021). Mangrove degradation from coastal development causes can be attributed to mangrove clearing, conversion to commercial, residential, agriculture, aquaculture and wake currents (Shahbudin et al., 2012). Additionally, pressures from port activities can impact ecological stability and reduce biodiversity (Isworo & Oetari, 2020).

Dredging

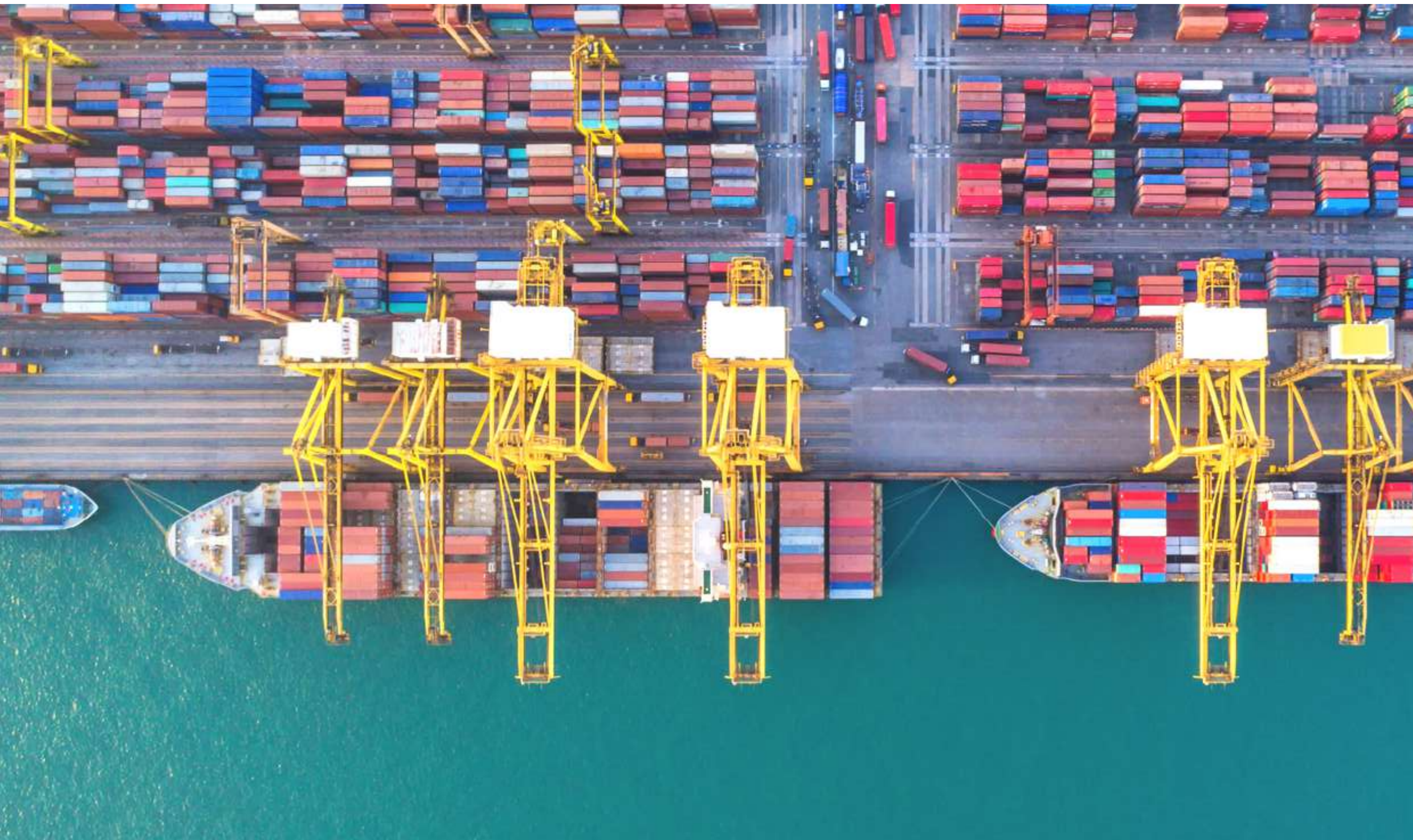
The development, operation and expansion of port activities often require ongoing dredging, backfilling and building within the coastal environment, disrupting surrounding sediment. Sediments in port areas are commonly polluted by a wide range of toxic materials that originate from port activities and the surrounding urban environment, settling on the underwater floor (Birch & Taylor, 2002). The disruption of these sediments often translates to the agitation and relocation of contaminated sediments to new disposal sites, adversely affecting nearby ecosystems (Chen et al. 2018).

Sensitive ecosystems such as coral reefs (Erftemeijer et al. 2012, Cunning et al. 2019) and seagrass beds (Erftemeijer & Lewis, 2006) can be negatively impacted by increased turbidity, shading from sediment plumes, smothering and burial by sediment as well as increased exposure to bacteria and disease. Dredging can also profoundly alter the coastal sediment dynamics of marine systems (OECD, 2011). Estuarine systems in particular have issues with dredging and the disposal of sediment and contaminated sediment, with the transitional zone between river and marine system having complex circulation and multiple distinct ecosystems impacted.

Channel deepening or straightening can lead to combined effects of tidal amplification, increasing estuarine circulation, and increasing flood-dominance of tidal asymmetry (Winterwerp & Wang, 2013) as well as deteriorating water quality due to increased suspended sediment concentrations (Maren et al. 2015).

Noise

Noise pollution in ports occurs both above and below the water, with multiple sources including ship engines, cranes and vehicles. The noise produced by shipping and ports can impact surrounding urban populations; it should be noted that in comparison to aviation and land vehicle noise, there are fewer people impacted by ports (OECD, 2011). However, the negative impacts of anthropogenic noise on marine organisms can be both direct and indirect, causing auditory masking, leading to cochlear damage, changing individual and social behaviours, altering body metabolism and hampering embryogenesis (Peng et al. 2015). Threats from noise caused by shipping, ports and related industry are not well understood and rarely considered within the development and operation of ports (Bennett, 2018). With ambient noise within ocean increasing, including within the WIO, there needs to be more research and regulation in place to lessen adverse impacts (Miksis-Olds, et al., 2013).



2.3 Ecological Assets Of Coastal & Marine Ecosystems

Ecosystem services or ecological assets are defined as ecological functions that sustain life, or the benefits and resources provided to humans that are obtained through living ecosystems (Francesconi, Srinivasan, Pérez-Miñana, Willcock, & Quintero, 2016). These are often less tangible than ecosystem goods, providing aesthetic, cultural or recreational benefits (UNEP-Nairobi Convention and WIOMSA, 2015). This is particularly the case in the WIO region, whereby tourism relies on important aesthetic, cultural, spiritual and historic sites, which often have been managed poorly in the past (UNEP-Nairobi Convention and WIOMSA, 2015).

Mangroves are an ecological asset of considerable importance. The WIO State of the Coast Report (UNEP-Nairobi Convention and WIOMSA, 2015) succinctly states the importance of mangroves to the local area. This includes:

- A habitat for many marine species, particularly during their breeding cycles, including fish and crustaceans of commercial importance;
- As a physical barrier to stabilise and protect shorelines against surges such as tsunamis;
- As a carbon sink, whereby mangroves are exceptional sequesters of carbon, mitigating against climate change; and
- Ecosystem goods such as food, firewood, medicines, etc.

Within coastal wetland settings, water quality has a pivotal impact on these ecosystem services, such as fisheries, tourism, and coastal protection (Barbier, et al., 2011). Water quality impacts on phytoplankton primary production, on which the entire marine ecosystem relies (UNEP-Nairobi Convention and WIOMSA, 2015).

Coastal development often results in high nutrient loads being delivered into the ecosystem, declining water quality, causing eutrophication and hypoxia and reducing the value of coastal habitat (Buelow & Waltham, 2020). Therefore, it is critical to understand the impacts of continued development within the WIO on local mangroves and water quality.

In addition, as part of the *Nairobi Convention* and WIOSAP project, member countries have committed to improving water quality to meet international standards by 2035 (UNEP-Nairobi Convention and WIOMSA, 2021).

3.

CASE STUDY: MOMBASA PORT KENYA

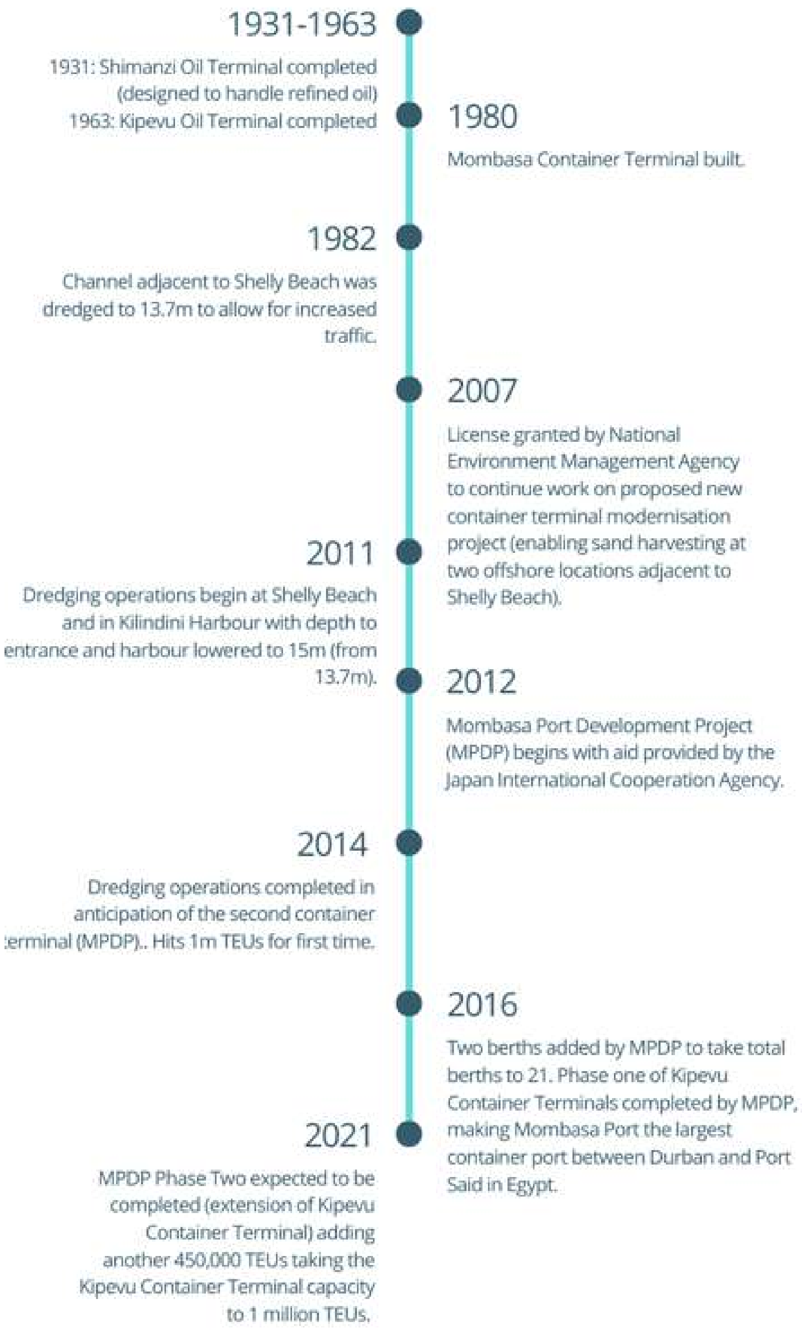
3.1 Case Study: Mombasa Port

Background & Current Infrastructure
Mombasa's trade origins date back to the 18th century, with Portuguese and Arab traders using the old port site located east of the current site near Mombasa Old Town.

In 1896 the first developments at the current site were made, with the then colonial British government establishing a port to facilitate the construction of the Kenyan-Ugandan Railway at the turn of the century. Since then, Mombasa Port has facilitated the movement of minerals, oil, dry bulk cargo, and played a role assisting British naval efforts in the Indian Ocean theatre during the Second World War.

From its inception in 1896, nineteen berths have been added to facilitate movement of minerals, goods and oil, with the latest berth added in 2016. In 1975 Mombasa Port moved it's first container; it's also now home to two oil terminals (the Shimanzi oil terminal being built in 1931 and the Kipevu oil terminal being built in 1963).

Of the two container terminals located in Mombasa Port, the total carry capacity is currently 2.65 million TEUs (twenty foot equivalent units), the largest in east Africa and the fifth largest on the continent (Kenyan Port Authority, 2021).



1931-1963

1931: Shimanzi Oil Terminal completed (designed to handle refined oil)
1963: Kipevu Oil Terminal completed

1980

Mombasa Container Terminal built.

1982

Channel adjacent to Shelly Beach was dredged to 13.7m to allow for increased traffic.

2007

License granted by National Environment Management Agency to continue work on proposed new container terminal modernisation project (enabling sand harvesting at two offshore locations adjacent to Shelly Beach).

2011

Dredging operations begin at Shelly Beach and in Kilindini Harbour with depth to entrance and harbour lowered to 15m (from 13.7m).

2012

Mombasa Port Development Project (MPDP) begins with aid provided by the Japan International Cooperation Agency.

2014

Dredging operations completed in anticipation of the second container terminal (MPDP).. Hits 1m TEUs for first time.

2016

Two berths added by MPDP to take total berths to 21. Phase one of Kipevu Container Terminals completed by MPDP, making Mombasa Port the largest container port between Durban and Port Said in Egypt.

2021

MPDP Phase Two expected to be completed (extension of Kipevu Container Terminal) adding another 450,000 TEUs taking the Kipevu Container Terminal capacity to 1 million TEUs.

Figure 3.1: Major Development Milestones at Mombasa Port since 1896.

Drivers of Growth

The drivers behind Mombasa Port's development have varied over the years. Initially being used by the British at the beginning of the 20th century for the purposes of developing the national rail network, it has since become one of the key trade links for Africa's many landlocked countries such as Ethiopia, South Sudan, Uganda, Burundi, Tanzania, and the Democratic Republic of Congo, all of which are reliant on imports. Of the entry and exit traffic through Mombasa Port, imports account for 90% of total cargoes with domestic requirements accounting for 70% of import traffic (JICA, 2015).

This reflects Africa's growing middle class, which has driven significant demand for consumer goods. To meet this demand, ocean freight supported by rail networks is the most efficient mode of transport for many dry bulk cargoes. This trend is expected to continue, with consumer spending growth in Africa expected to rise to $2.5 trillion USD by 2030, double the 2015 figure (Brookings, 2018). Out of the top ten fastest consumer growing markets in Africa, Mombasa Port currently facilitates traffic to four of these markets, as seen in Figure 3.2. Exports make up a significantly smaller proportion of all traffic, yet still remains a valuable and growing aspect of Mombasa Port. Oil, tea, soda ash, coffee, and other agricultural products are exported from Kenya across the globe; this is expected to continue into the future.

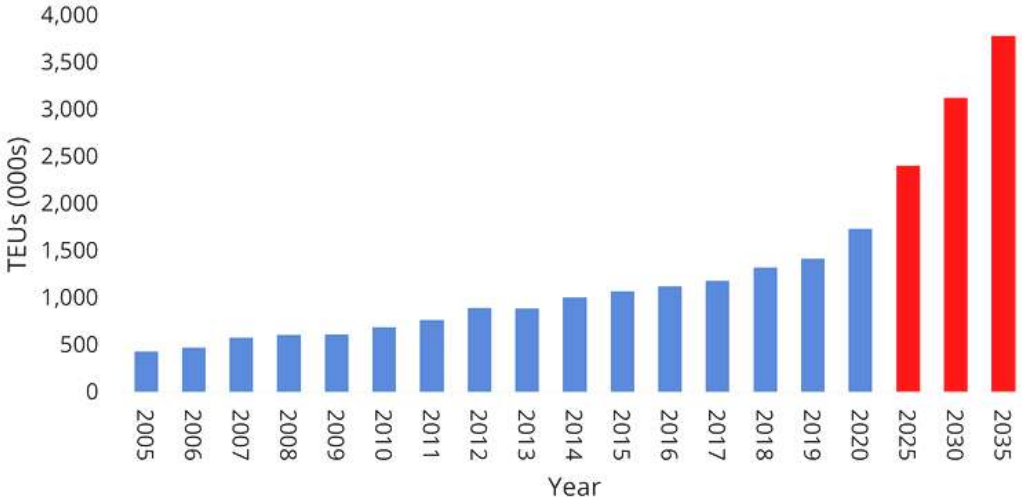


Figure 3.2: Demand Forecast and Historical Data Container Cargoes at Mombasa Port (000s TEU, 2025 onwards are projections in red) (Kenyan Port Authority, 2021).

Foreign investment in Mombasa Port has been a significant driver of growth in recent times. With the demand for consumer goods a direct result of a growing African middle class, China is a major beneficiary. Mombasa Port is used as a conduit to import Chinese products into Africa at scale; the Chinese government has ensured that Mombasa Port infrastructure has kept pace to meet demand for imports over the past decade with Chinese financiers backing infrastructure projects such as the upgraded national rail network in the region since 2016. This is expected to continue as container cargo growth since 2015 has been 7% on average and is predicted to increase to 20% with the expansion of the second container terminal in late 2021 (CEIC Data, 2019).

The Japanese government has also invested in Mombasa Port in the past twenty years. In 2012 the *Mombasa Port Development Project* began with the financial support of the *Japanese International Cooperation Agency*, including the addition of a new container terminal in 2016 and its ongoing expansion. This ongoing financial support and expansion is expected to continue well beyond it's slated timeline of 2022. Foreign investment is complemented by the Kenyan government's overarching strategy to drive economic development across several industries, titled *Kenya Vision 2030*. Identifying Kenya as a newly industrialised country, the plan aims to achieve an annual GDP growth rate of 10% through infrastructure developments such as the *Mombasa Port Development Project*.

Future Projections

Mombasa Port looks set to benefit well into the future from increased consumer demand, modest export potential, and willingness from governments to invest in the region in return for access to growth markets. COVID 19 has checked growth in the region, and globally, for the period from early 2020 until at least 2022. However, with vaccination potential on the horizon this is expected to be a short term lull in trade. The *Kenyan Port Authority* (KPA) estimates that there will be continued growth well beyond the holding capacity at the two current container terminals. It is one of a handful of ports that have been flagged as nearing maximum operational capacity on the east African coast. Current TEU carrying capacity is 2.65 million, with capacity expected to be exceeded by 2025 (Maritime Executive, 2021).

Lamu Port

In contrast to Mombasa Port, which has existed for over a century, Lamu Port has only recently been completed as a priority infrastructure project in northern Kenya. With plans to reduce the reliance on Mombasa Port by creating a "mega infrastructure" project at Lamu, 240km north of Mombasa, three of the proposed thirty-two berths for Lamu Port have already been built. Intense competition capitalise on growth in the regions has led to significant investment in Lamu Port. Notwithstanding the potential to compete domestically with Mombasa Port, Djibouti Port is also a source of potential competition as the stakes are raised to win substantial contracts from international shipping companies.

The perceived way forward for Lamu is to focus on further developing the site in order to provide greater value to prospective clients in the race to service the east Africa region, in particular South Sudan and Ethiopia. Lamu Port has been funded by the *China Communication Construction Company* and the site will eventually entail a railway, an oil pipeline and refinery, new roads, an airport, and resorts. Initial costs for the three berths are $480 million USD (Journal of Commerce, 2016).

Lamu Port is an example of further development in the region having an impact on marine and terrestrial ecosystems near the site, as well as sociocultural impacts on those living in proximity. Whereas Mombasa Port is relatively mature in terms of development, Lamu Port has a significant amount of development to be implemented and poses a challenge to integrate into the surrounding ecosystems and minimise disruption.

3.2 Historical Cases Of Pollution At Mombasa Port

There have been six significant oil spills within the Mombasa area, beginning with a spillage in 1972, all of which have contributed to extensive dieback and damage to surrounding mangrove forests (Abuodha and Kairo, 2001, Richmond, 2002). The smothering of mangroves, vegetation and organisms have been the most significant effect of oil spills, however, the toxic derivatives of oil continue to have long-term impacts on the environment (Duke et al. 1997, Abuodha and Kairo, 2001).

There is limited data available on operational pollution from ships in the region. Furthermore, none of the WIO region countries have comprehensive monitoring of marine pollution programs to determine the extent of shipping-related pollution (UNEP-Nairobi Convention and WIOMSA, 2015). Studies have found chemical pollution, specifically, that of copper, cadmium, iron and zinc have been found within the Kilindini and Makupa creeks of Mombasa (Kamau, 2001). Additionally, elevated levels of cadmium, copper, lead and zinc have been found in Port Reitz creek sediment (Munga et al. 2007). The location of studies suggests pollution sources could originate from port activities.

Mohamed and others (2009) examined mangrove ecosystems at Tudor Creek, Mombasa, finding them to be degraded due to the anthropogenic pressures from the nearby port and urban areas. With continued stress there can be a shift in mangrove extent and the ecosystem services they provide, making way for a less productive land use type. It is critical to note that land-use changes associated with Mombasa Port have also forced the involuntary resettlement, interference, demolition or relocation of structures with cultural or religious significance (Earth Matters Consulting, 2006). This is unlikely to be isolated to Mombasa, as land-use changes for port development in Lamu have impacted indigenous communities, livelihoods and a cultural sense of place in complicated ways (Chome, 2020).

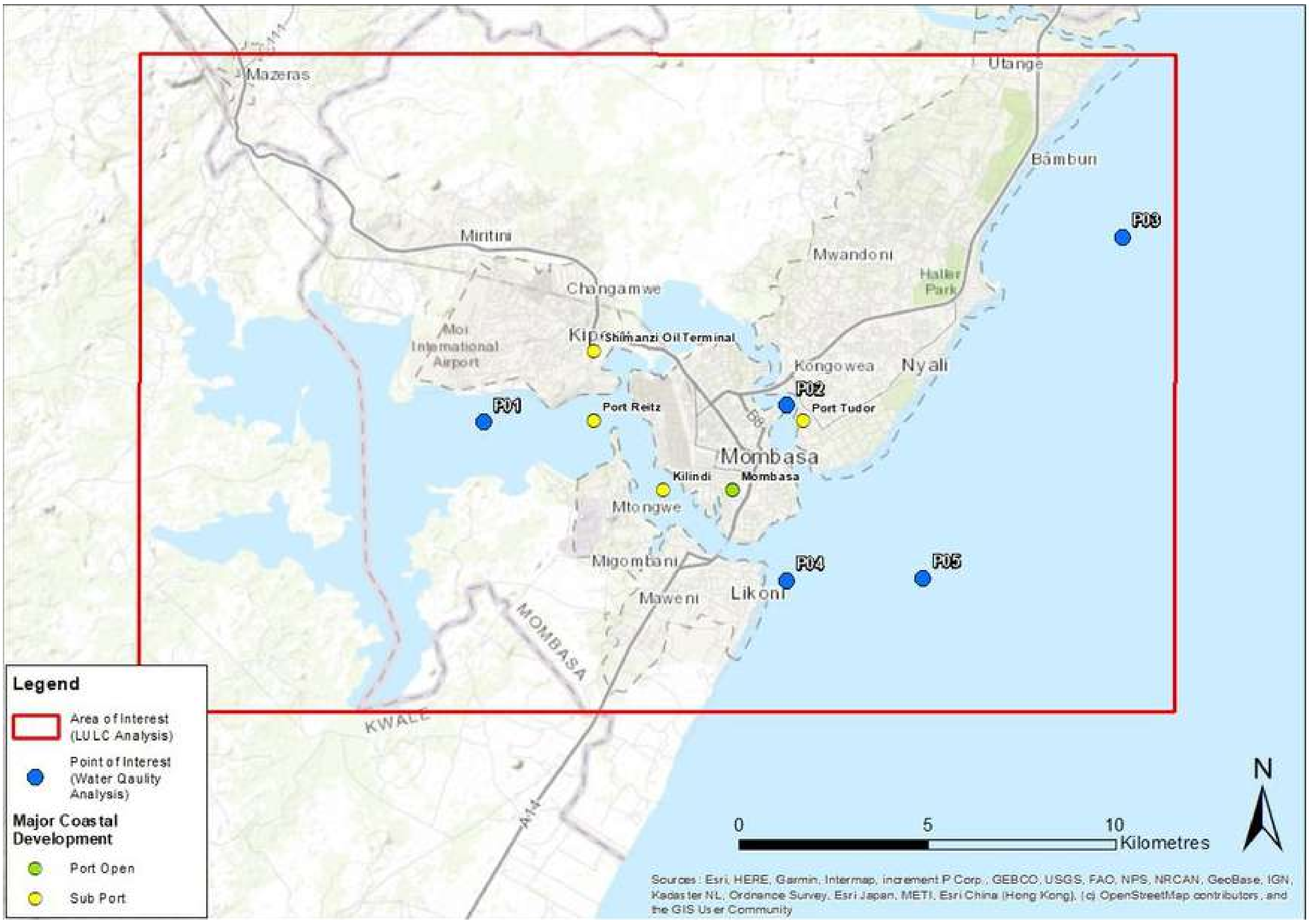
The dredging activities of Mombasa Port in particular have impacted the surrounding ecosystems by contributing to high suspended solids. This is evident in high sediment loading affecting the coral reefs, seagrasses, fish habitats (Kazungu et al., 2002) and the degradation of mangrove forests located in the Mwache Estuary (Kitheka et al., 2003). The deposition of dredged material from Kilindini Harbour in Mombasa in deep waters beyond the reef has been found to contain significant amounts of particulate material and noxious chemicals, such as nutrients, heavy metals and organic compounds (Munga et al., 2007). Furthermore, the loss of beach frontage for some developments in Kenya through sediment deposition and beach accretion has impacted tourism (Kazungu et al., 2002).

4.

METHODOLOGY

4.1 Introduction

Land use and land change and water quality were analysed to understand the rate of change and implications for ecosystem assets, using Mombasa Port as a case study. The following outlines the general methodology followed to undertake the analysis. Figure 4.1 shows the area of interest used in the land use and land change analysis, and the points of interest used in the water quality analysis.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 4.1: Area and Points of Interest for GIS Analysis at Mombasa Port

4.2 Water Quality Methodology

Initially, *Sentinel* data was used to give high resolution water quality information, however significant temporal data gaps occurred and it was concluded that a temporal analysis of the water quality parameters was the best method to understand broad trends in water quality over time. Therefore, data was sourced from the open-source online platform *GlobColour*, which comprises data built from numerous satellite sensors, outlined in Table 4.1.

The three parameters used to assess water quality include:

- CHL1 - Chlorophyll concentration (mg/m3), as a proxy for phytoplankton biomass or primary productivity, merges data from all sensors using weighted averaging (AVW) and GSM model (GSM) techniques. The level of chlorophyll provides an insight into the aquatic ecosystem health as phytoplankton is the foundation of the marine food web (UNEP, 2015). A reduction will likely lead to a reduction in other available species, whilst too much indicates the presence of algal blooms which can result in fish kills;
- TSM - Total suspended matter concentration (g/m3), as a proxy for total suspended solids, merges data from MERIS, OLCI-A & OLCI-B sensors using simple averaging (AV). Suspended matter, or solids, in high concentrations increases the absorption of light in the water column and therefore reduces oxygen availability, which is critical for many aquatic species (Verma & Singh, 2013);
- KDPAR - Diffuse attenuation coefficient for the Photosynthetically Available Radiation (m-1), as a proxy for turbidity, merges data from all sensors using analytical averaging from other L3 products. This assesses light availability within the water column and provides an indication of the concentration of pigments, such as chlorophyll-a, and TSM. It can determine the euphotic zone in coastal areas, impacting the type and distribution of algal species (Saulquin et al., 2013).

Table 4.1: GlobColour sensor information, from ACRI-ST GlobColour (2020)

Sensor	Resolution	Start Date	End Date	Reprocessing Version
SeaWiFS	GAC 4km	1997-09-04	2010-12-11	NASA R2018.0
MERIS	RR 1km	2002-04-28	2012-04-08	ESA 3rd reprocessing
MODIS AQUA	1km	2002-07-03	Present	NASA R2018.1
VIIRS NPP	1km	2012-01-02	Present	NASA R2018.0
OLCI-A	RR 1lon	2016-04-25	Present	ESA PB 2.16 to 2.55
VIIRS JPSS-1	1km	2017-11-29	Present	NASA R2018.0
OLCI-B	RR 11cm	2019-03-25	Present	ESA PB 1.14 to 1 27

The method used to analyse the water quality data is summarised in Figure 4.2. The raw data was combined into one timeseries file per parameter and extracted for visualisation and analysis using RStudio with the 'raster', 'rgdal', 'ncdf4' and 'sp' statistical packages. Yearly averages were taken for each water quality parameter to provide an indication of how the water quality has changed over time. By taking an average it reduces the impact of seasonal implications such as the local monsoon seasons or data outliers on water quality, and provides a broad understanding of trends. A summary using Microsoft Excel allowed for fast manipulation of the monthly data into a yearly average, which was then plotted onto a time-series graph.

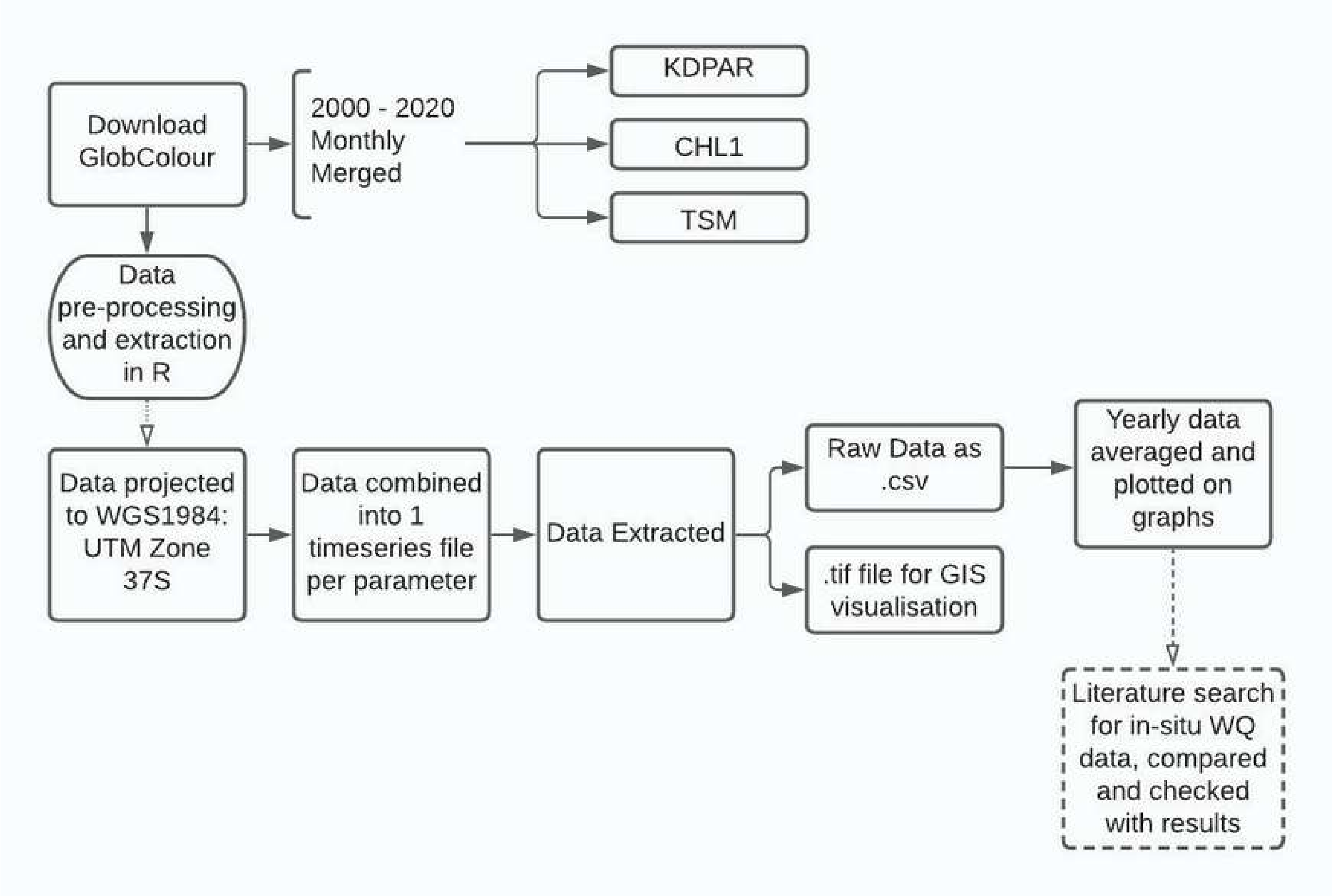
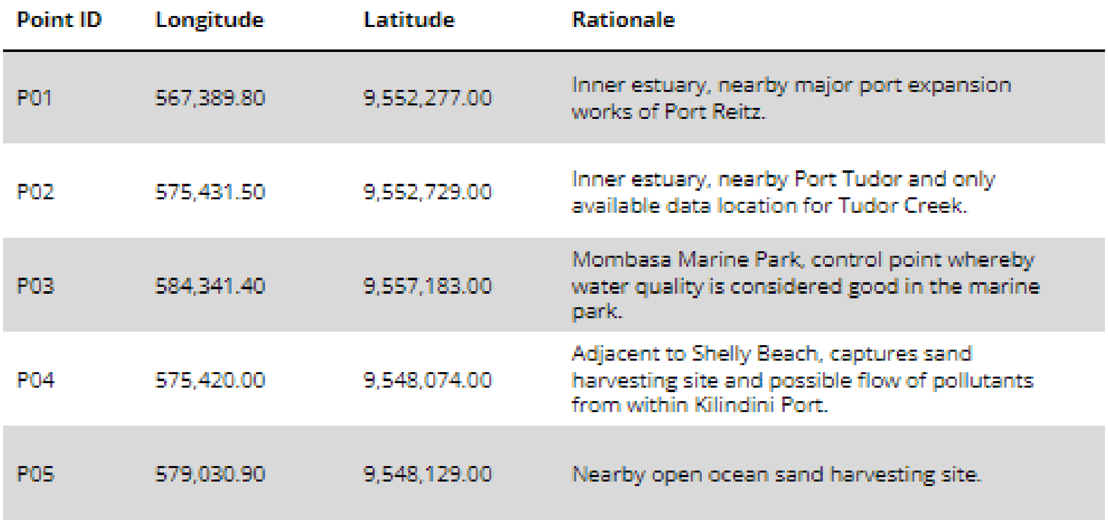


Figure 4.2: Workflow procedure for water quality analysis.

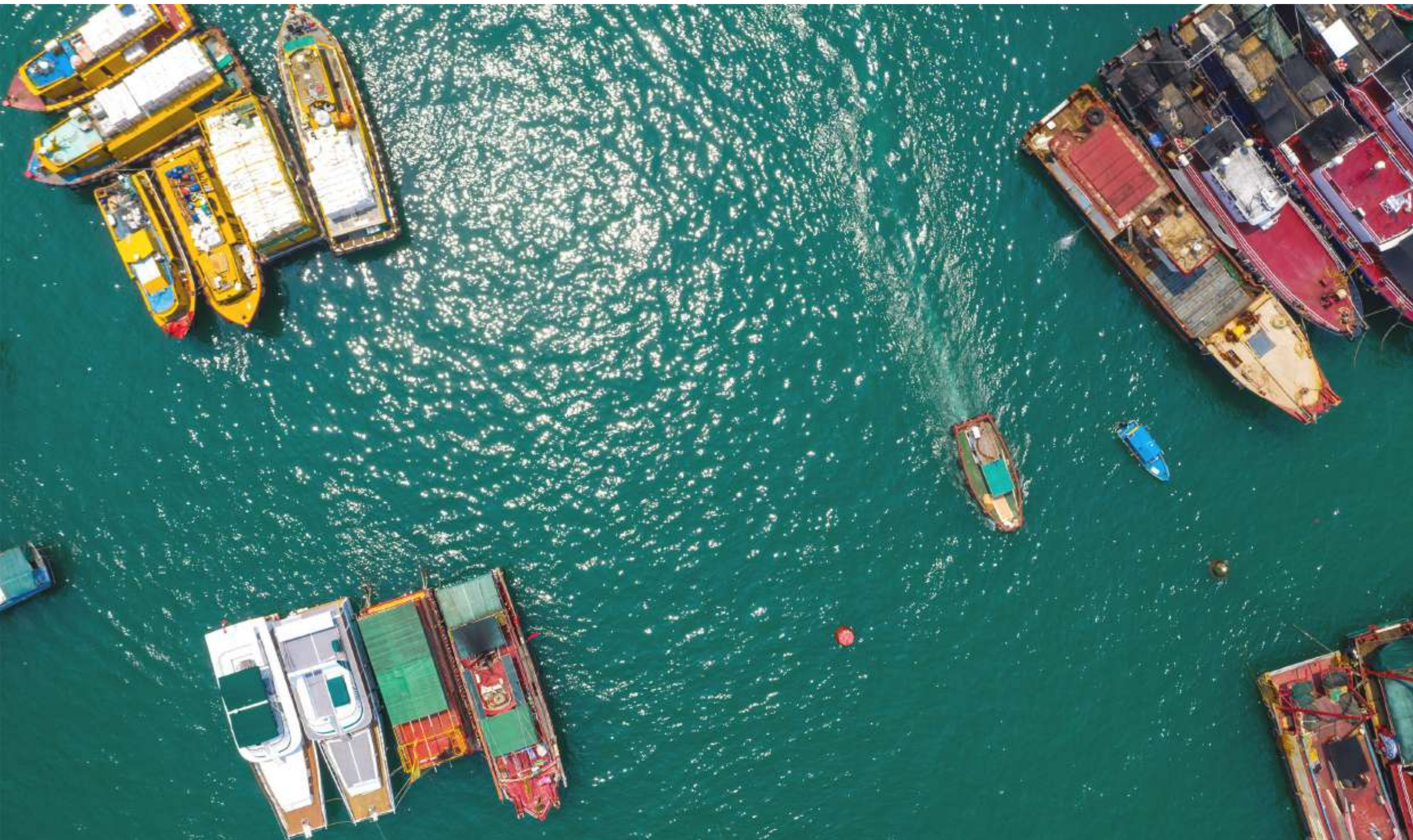
Methodology

The point locations used for analysis (P01 to P05) were chosen based on a combination of known areas of interest for the site and locations with available data. A summary of rationale behind each point location is provided below in Table 4.2.

Table 4.2: Point location information.



Point ID	Longitude	Latitude	Rationale
P01	567,389.80	9,552,277.00	Inner estuary, nearby major port expansion works of Port Reitz.
P02	575,431.50	9,552,729.00	Inner estuary, nearby Port Tudor and only available data location for Tudor Creek.
P03	584,341.40	9,557,183.00	Mombasa Marine Park, control point whereby water quality is considered good in the marine park.
P04	575,420.00	9,548,074.00	Adjacent to Shelly Beach, captures sand harvesting site and possible flow of pollutants from within Kilindini Port.
P05	579,030.90	9,548,129.00	Nearby open ocean sand harvesting site.



4.3 LULC Methodology

The LULC analysis was carried out using *ESRI ArcMap* software with data provided by UNEP. The first part of the methodology for LULC involved organising each individual file in order to prepare them for intersection, as seen in Figure 4.3. In the first section the analysts renamed the 'LULC_20XX' with specific years for example: 'LULC_2001' or 'LULC_2002'. The second section continued the analysis and identified the changes in land use, as seen in Figure 4.3.

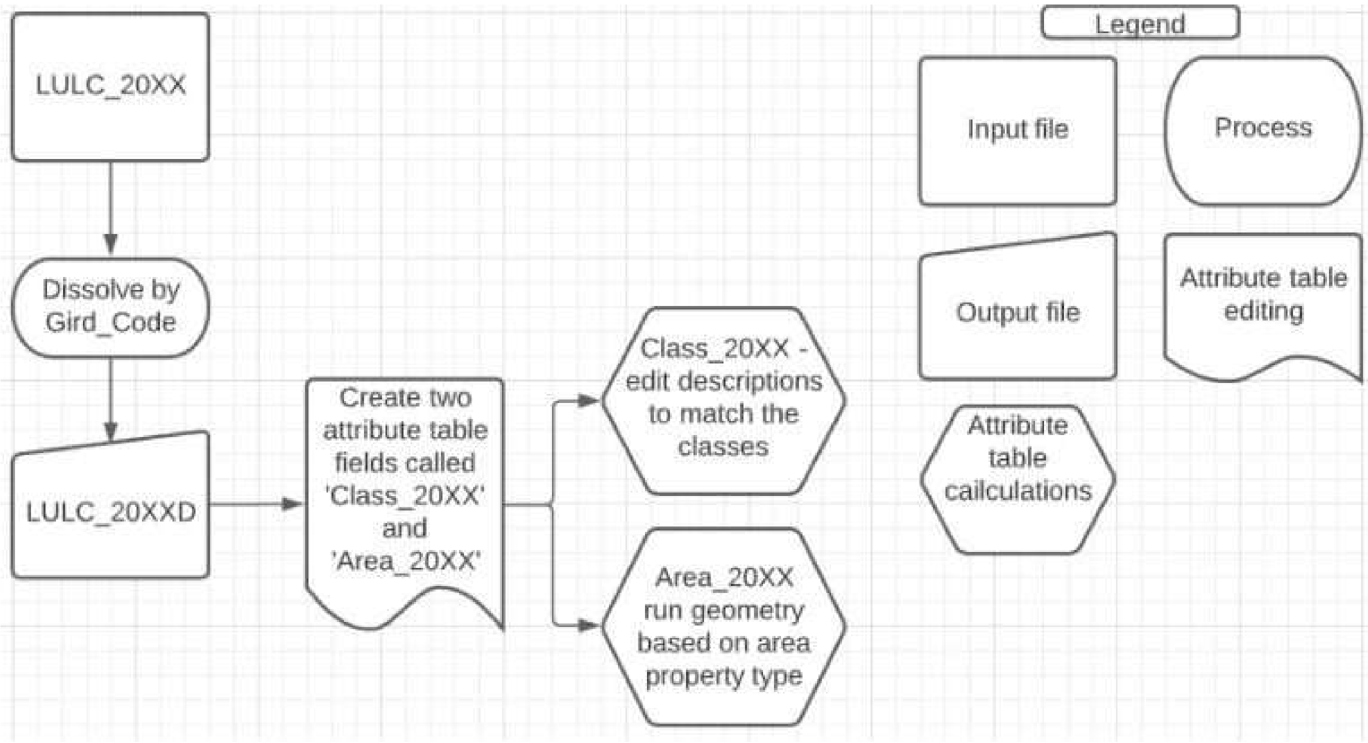


Figure 4.3 Part 1: Setting up the individual files.

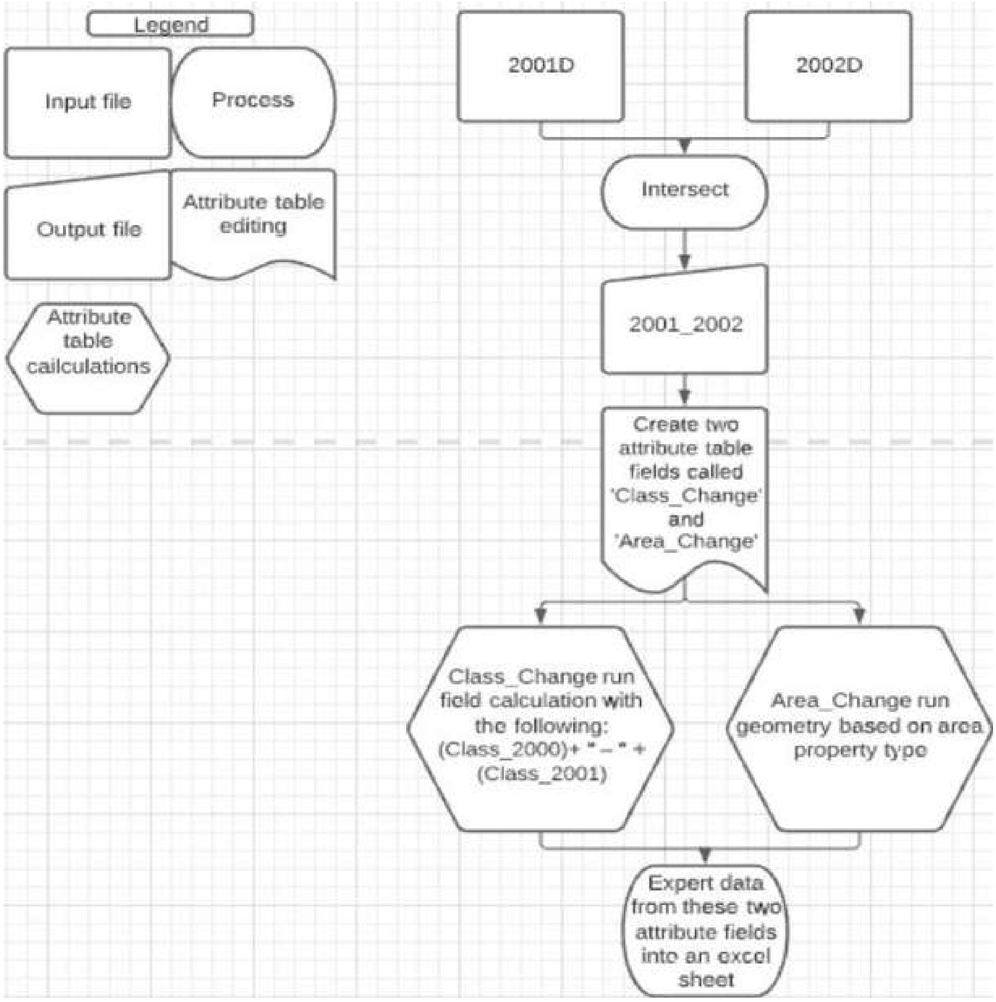


Figure 4.3 Part 2: Intersection of files and exportation to excel.

Data was supplied by UNEP for analysis. The data comprised the WIO region and an Area of Interest (AOI) was selected to cover the scope of Mombasa Port. The data had some minor issues, including anomalies within the waterbody classification where mangroves were displaying within the waterbodies. In order to counter this, the unwanted anomaly data was masked and erased. Overall, the GIS data for LULC was well prepared and had minimal issues, the following land use types were identified and provided by the client:

- Built-up
- Bare Soil
- Sparse Forest
- Forest
- Agriculture
- Water Bodies
- Mangroves

The analysis aims to identify and quantify major change in land use during the period of 2000 to 2020. Individual years during the time period were assessed to understand yearly percentage change and highlight years in which large changes occurred.

5.

RESULTS

5.1 Water Quality Results

Chlorophyll

The results for average CHL1 concentrations over time are displayed in Figure 5.1. P01 is shown separately in Figure 5.1 due to its data gaps and high concentration of CHL1 relative to the other points. At P01, CHL1 levels ranged from 0.6 mg/m3 in 2012 to 30 mg/m3 in 2007.

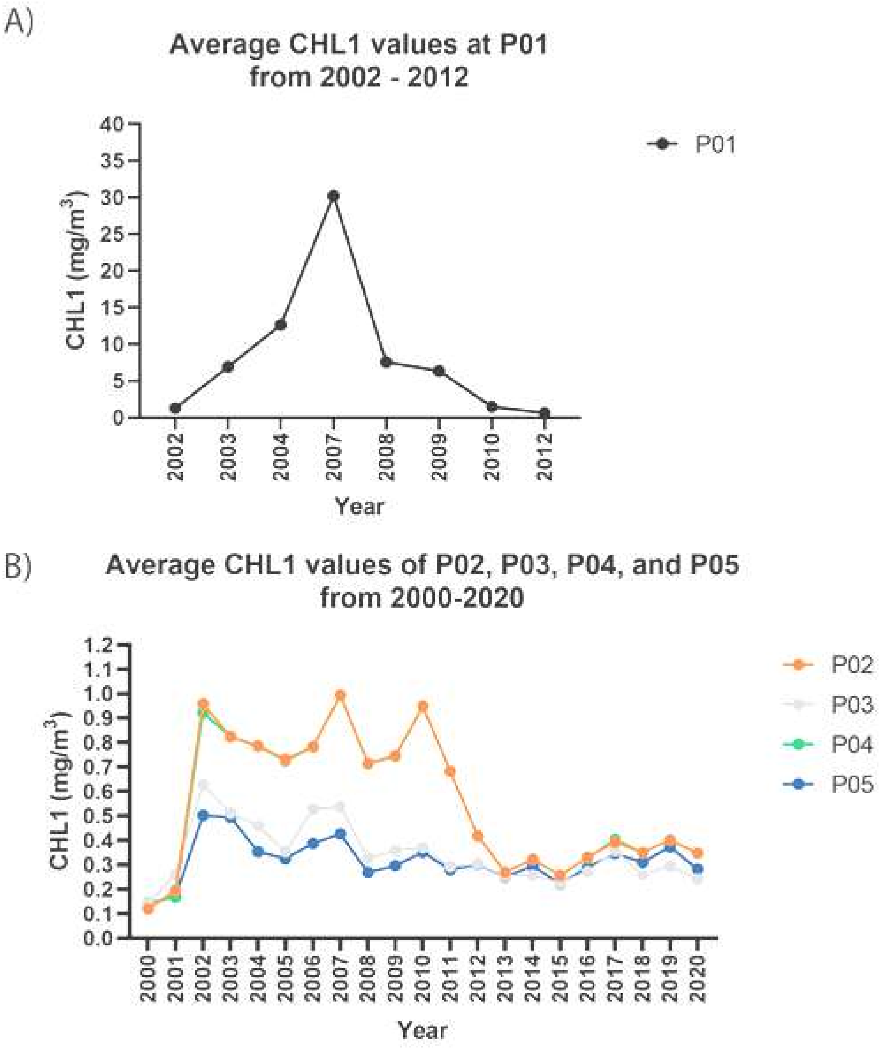


Figure 5.1 A) Showcases the average CHL1 values at the PO1 site from 2000 to 2020, however data was only available from 2002 to 2012. B) Showcases the average CHL1 values at the PO2, PO3, PO4 and PO5 sites from 2000 to 2020.

All other locations range from 0.1 to 1.0 mg/m3 of CHL1 over the 20 year period. P02 and P04 recorded significantly higher levels (0.41 to 0.99 mg/m3) of CHL1 from 2002 to 2013 than P03 and P05 (0.22 to 0.62 mg/m3) and remained higher until 2020.

Total Suspended Matter

There is a significant data gap for TSM from 2012 and therefore results are for prior to then. TSM results shown in Figure 5.2 below indicate that TSM was highest at P01 from 2005 to 2012, however was higher at P02 and P04 prior to that. TSM fluctuated at P01 (1.89 to 5.29 g/m3), although it shows a general increasing trend. TSM levels at all other locations appear to remain relatively stable from 2002 to 2012, with P02 and P04 mostly just below 3 g/m3 and P03 and P05 between 0.2 and 0.8 g/m3.

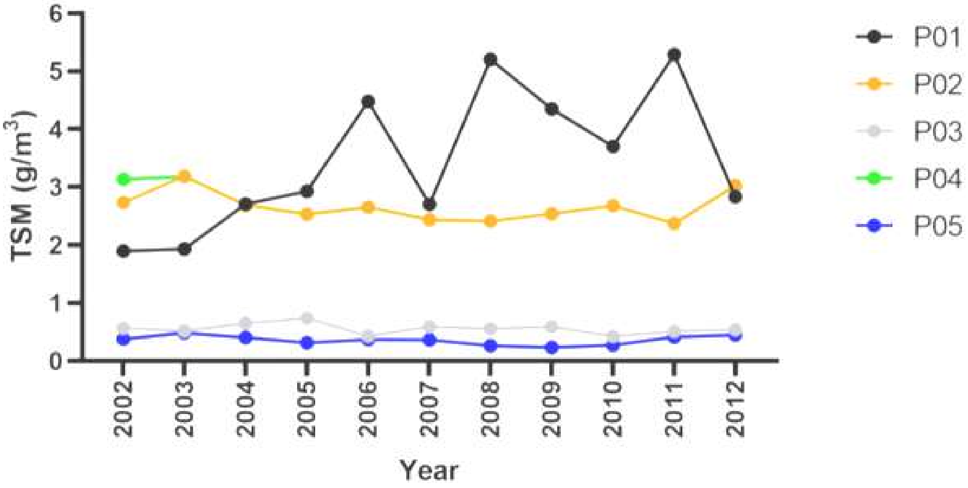
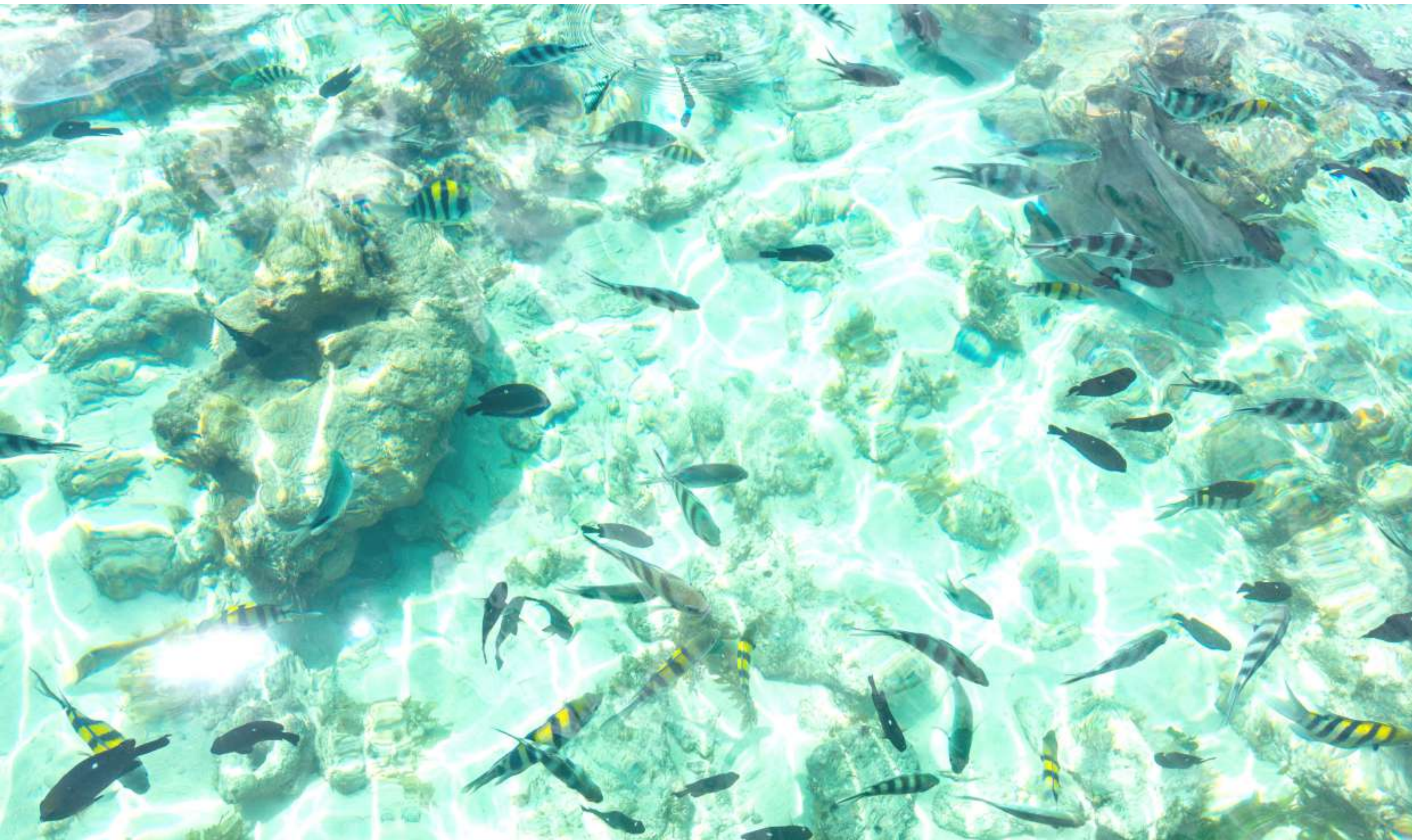


Figure 5.2: Showcases the average TSM values at all locations from 2000 to 2012.



Turbidity

Figure 5.3 A shows the turbidity, as measured by KDPAR, results at P01, which were significantly higher than at all other locations, ranging from 0.3 to 0.56 m-1. The highest recorded turbidity values at P01 were in 2007 and 2016, whereas at other locations (Figure 5.3 B) the highest recorded values were in 2000 and 2002. P05 consistently recorded the lowest turbidity and ranged from 0.079 to 0.098 m-1.

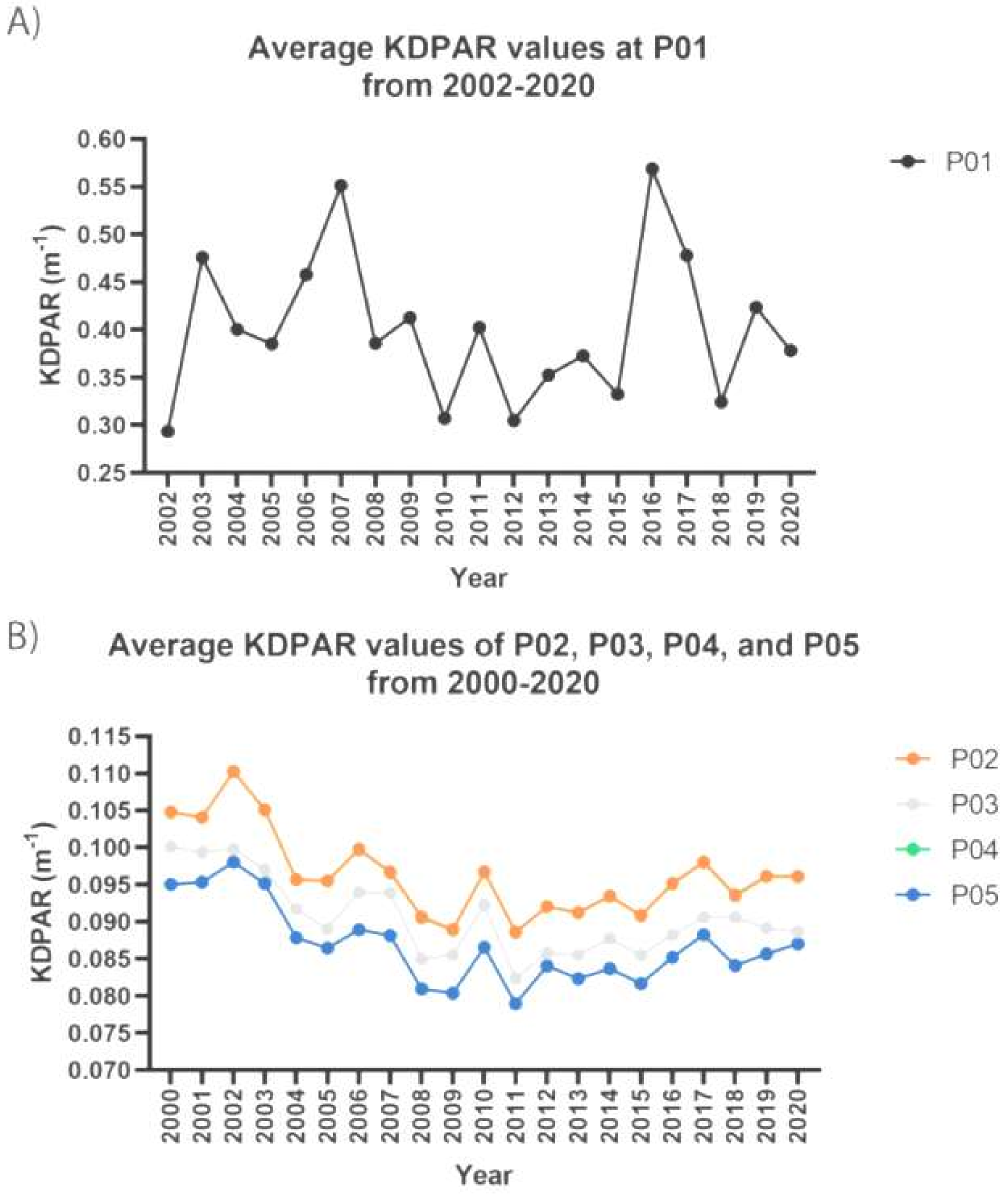


Figure 5.3 A) Showcases the average KDPAR values at the P01 site from 2000 to 2020. B) Showcases the average KDPAR values at the P02, P03, P04 and P05 sites from 2000 to 2020.

5.2 LULC Results

The analysis identifies and quantifies major change in land use during the period of 2000 to 2020, as seen in Figure 5.4 below.

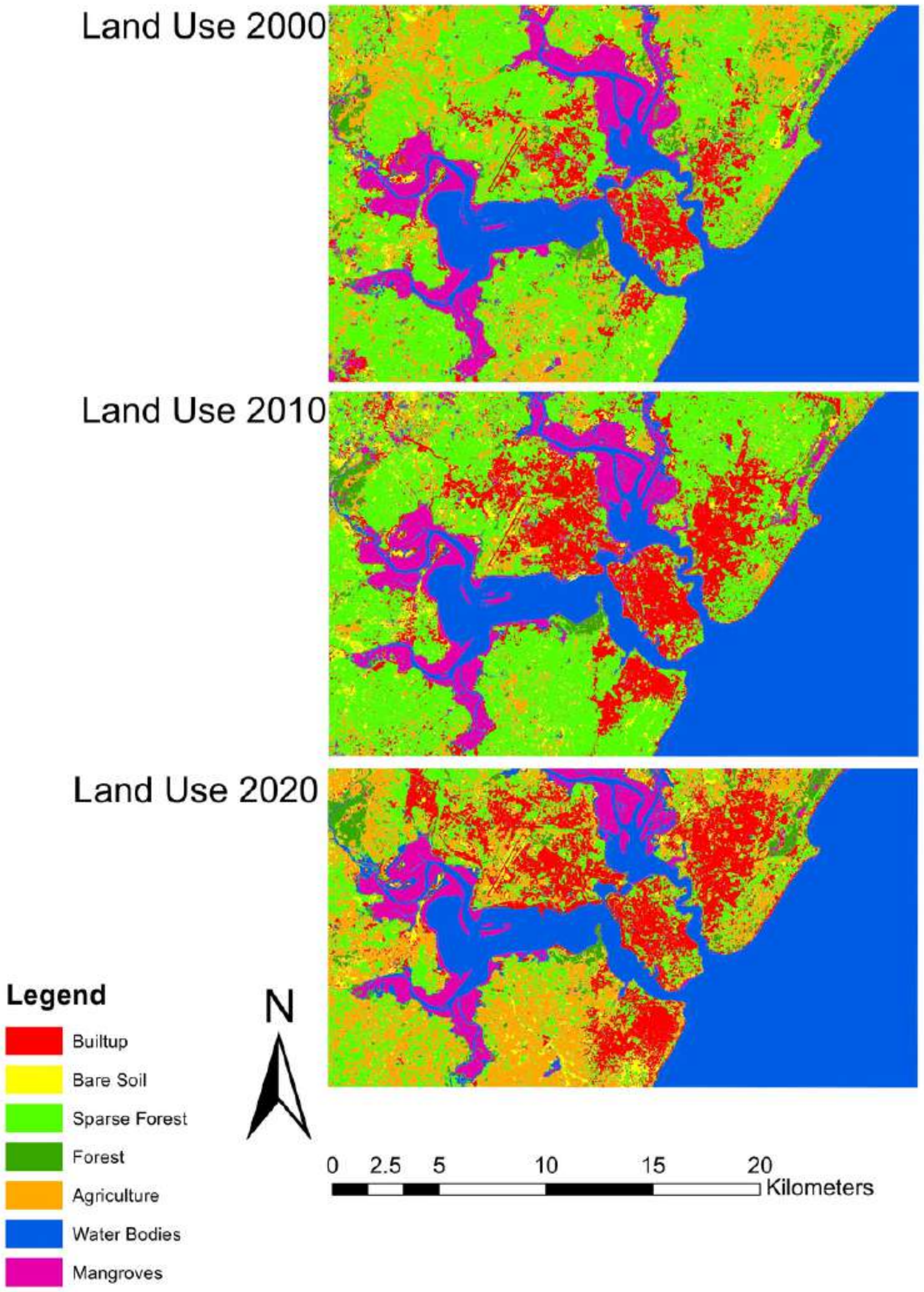


Figure 5.4: Side-by-side map comparison of the Mombasa region highlighting the years 2000, 2010 and 2020. The map showcases different class features as shown in the legend and how they change over time.

Built Up and Bare Soil Changes

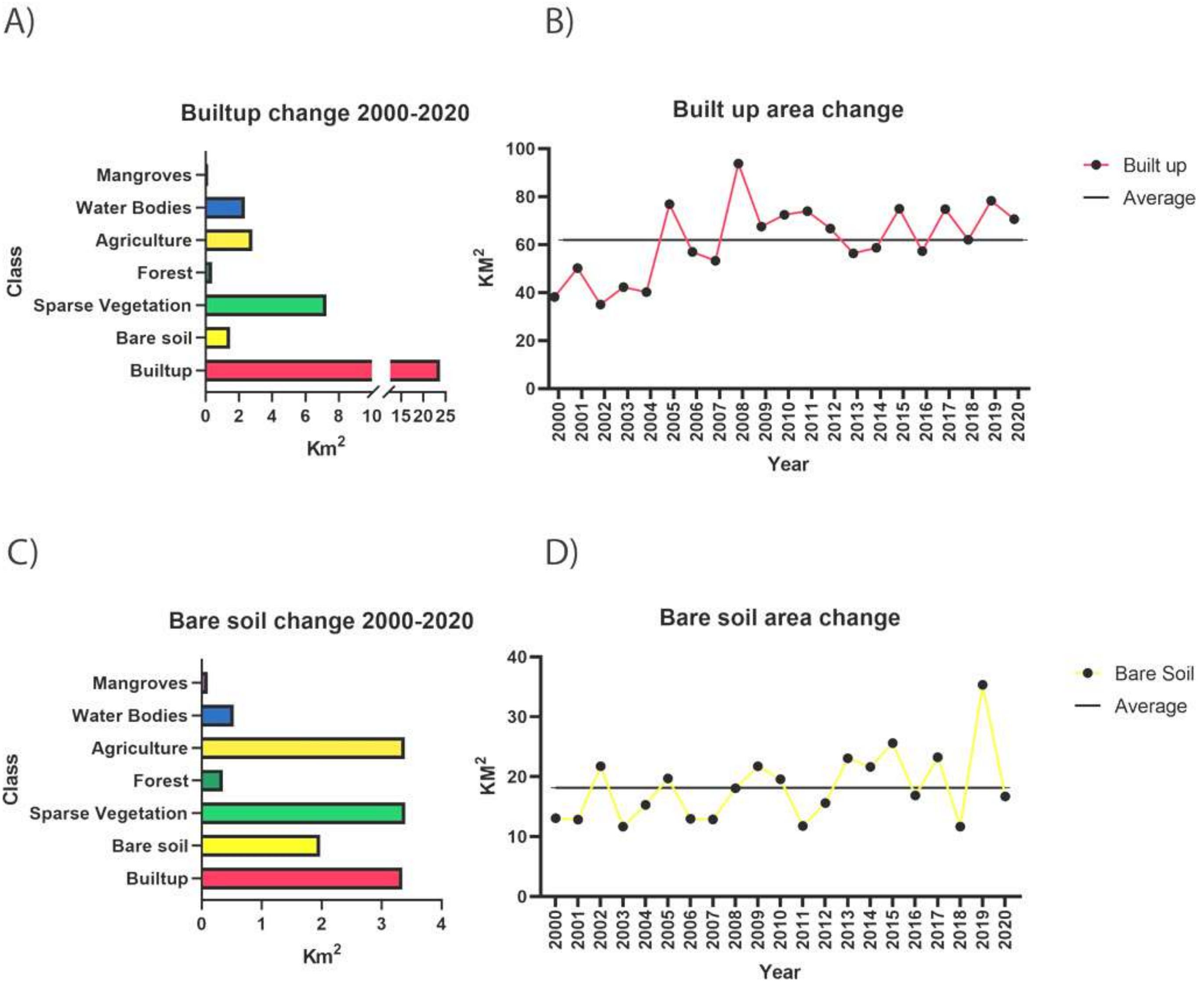


Figure 5.5 A) showcases the built up area change into each of the seven specified classes, The change highlighting 'built up to built up' represents any original built up that has been retained over the 20-year period. B) showcases the built up area change over time regardless of which class it had been lost to or which classes it had been gained from. C) showcases the Bare Soil area change into each of the seven specified classes, The change highlighting 'Bare Soil to Bare Soil' represents any original Bare Soil that has been retained over the 20-year period. D) showcases the Bare Soil area change over time regardless of which class it had been lost to or which classes it had been gained from.

Sparse Vegetation and Forest Changes

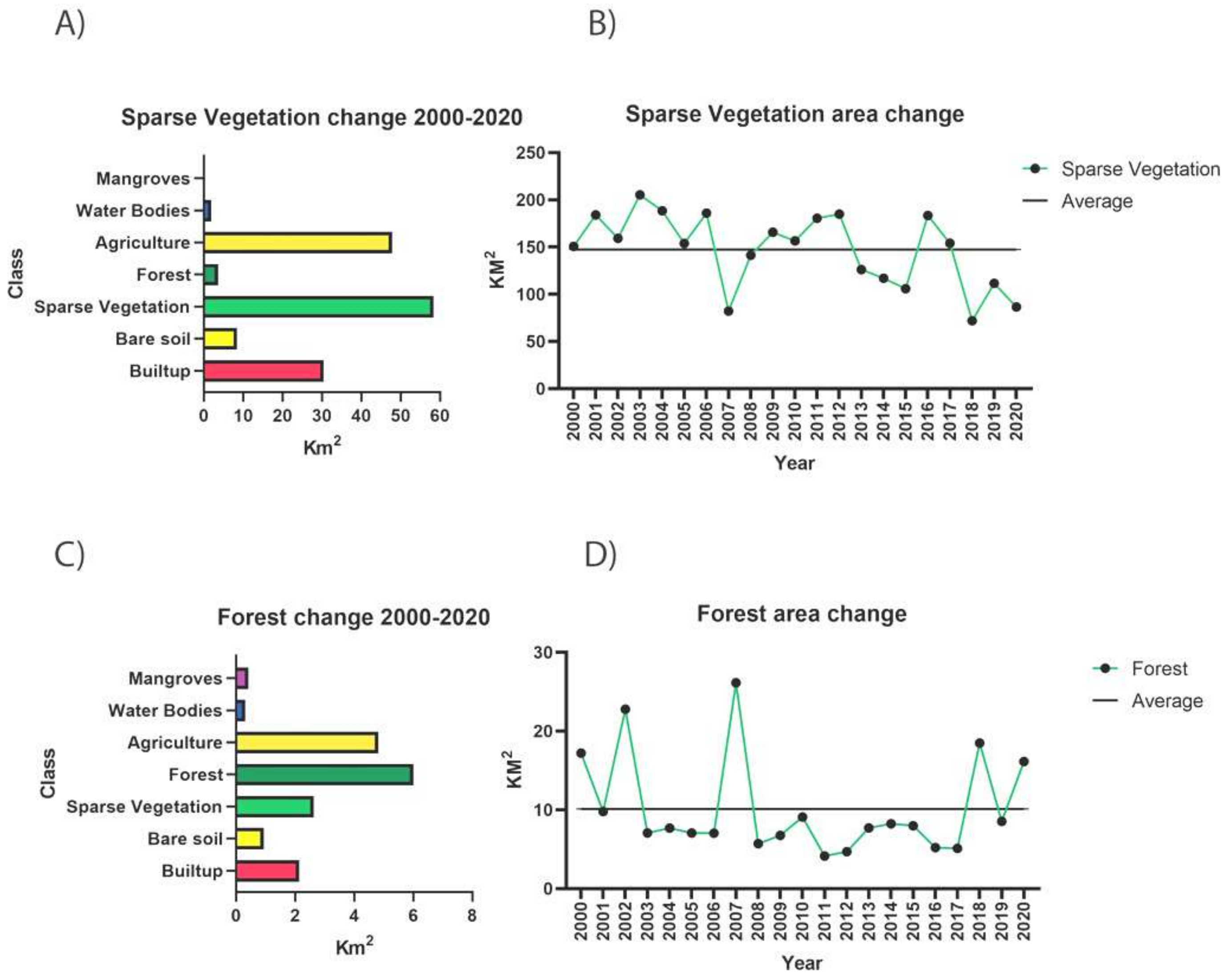


Figure 5.6 A) showcases the Sparse Vegetation area change into each of the seven specified classes, The change highlighting 'Sparse Vegetation to Sparse Vegetation' represents any original Sparse Vegetation that has been retained over the 20-year period. B) showcases the Sparse Vegetation area change over time regardless of which class it had been lost to or which classes it had been gained from. C) showcases the Forest area change into each of the seven specified classes, The change highlighting 'Forest to Forest' represents any original Forest that has been retained over the 20-year period. D) showcases the Forest area change over time regardless of which class it had been lost to or which classes it had been gained from.

Agriculture and Waterbodies

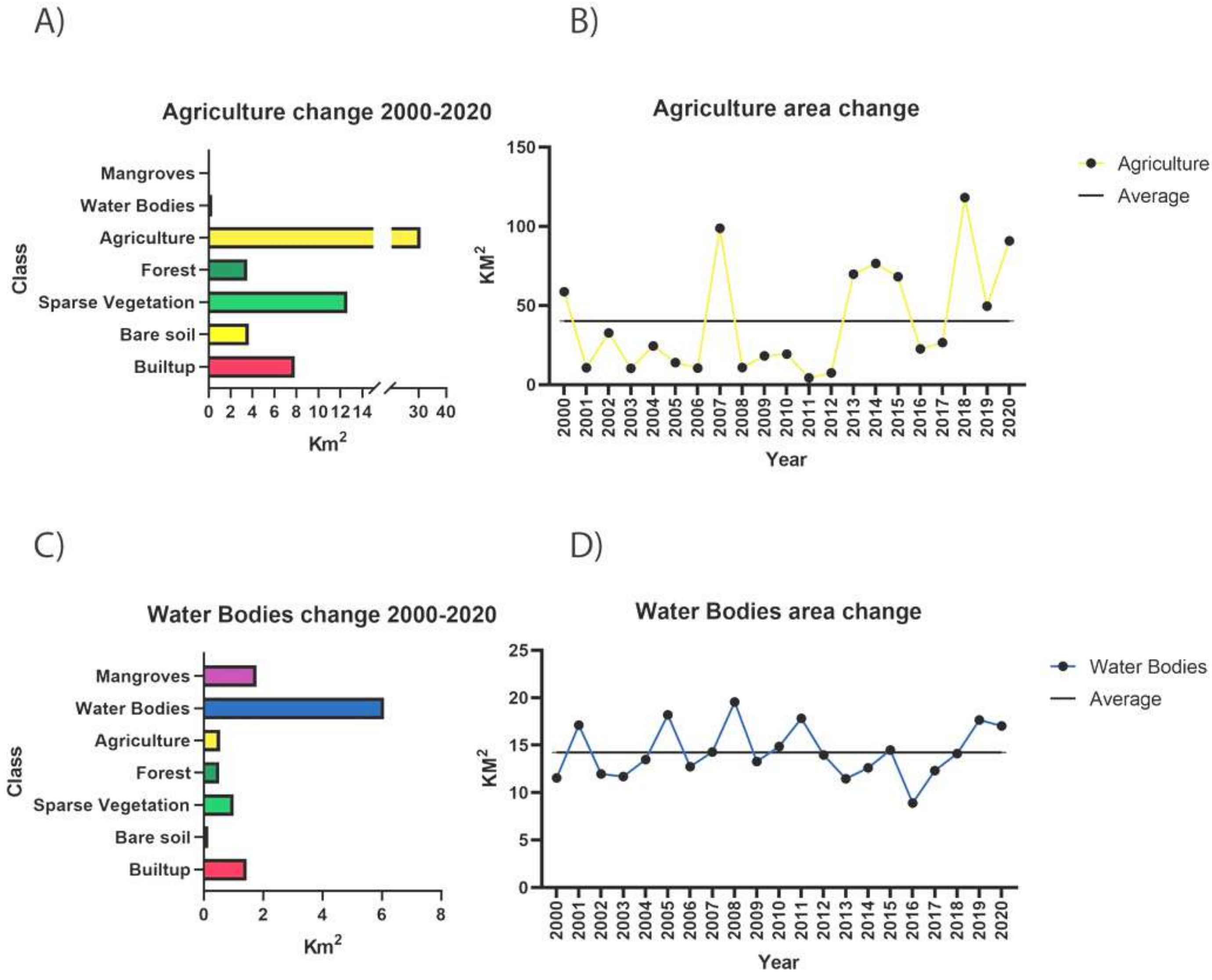


Figure 5.7 A) showcases the Agriculture area change into each of the seven specified classes, The change highlighting 'Agriculture to Agriculture' represents any original Agricultural land that has been retained over the 20-year period. B) showcases the Agriculture area change over time regardless of which class it had been lost to or which classes it had been gained from. C) showcases the Water Body area change into each of the seven specified classes, The change highlighting 'Water Bodies to Water Bodies' represents any original Water Body that has been retained over the 20-year period. D) showcases the Water Body area change over time regardless of which class it had been lost to or which classes it had been gained from.

Mangroves

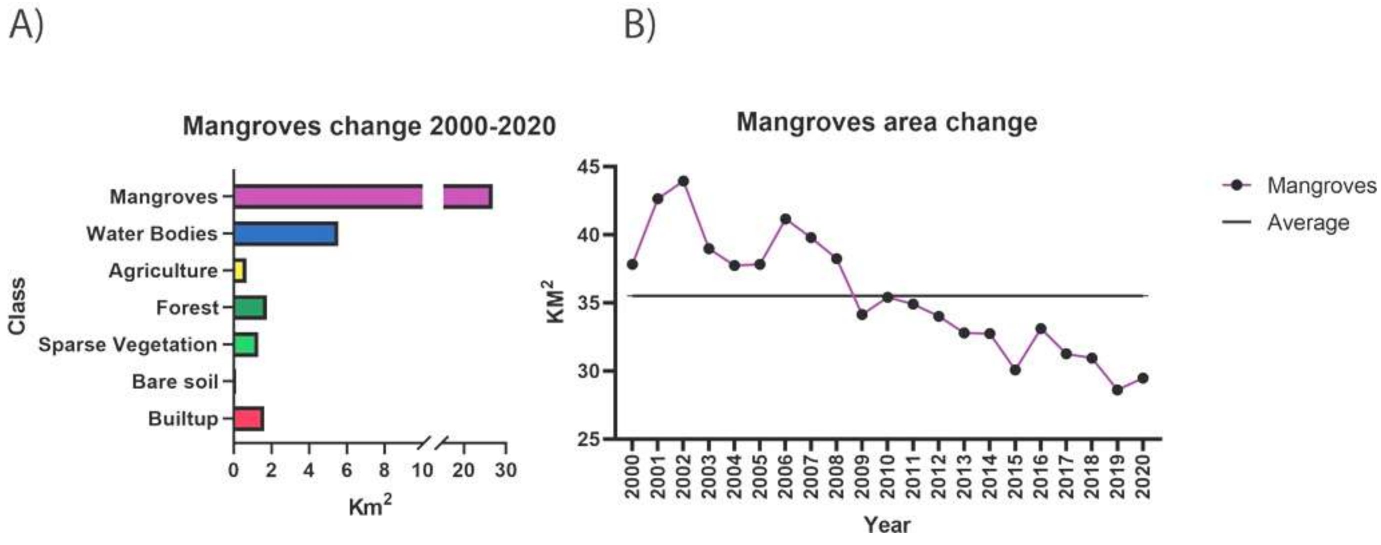


Figure 5.8 A) showcases the Mangrove area change into each of the seven specified classes. The change highlighting ‘Mangrove to Mangrove’ represents any original Mangroves that has been retained over the 20-year period. B) showcases the Mangrove area change over time regardless of which class it had been lost to or which classes it had been gained from.

6.

DISCUSSION

6.1 Water Quality Discussion

Within Mombasa, the Port Reitz estuary and creek is a significant asset providing an array of goods and services, particularly as a major fishing ground for local artisanal fishers (Earth Matters Consulting, 2006). P01 is placed directly in this estuary area (Figure 4.1) and is seen to have increased concentrations of all water quality parameters. Whilst undertaking an environmental impact assessment, Earth Matters Consulting (2006) noted that because of marine vessel pollution, port operations, dry cargo releases and industry discharges, water quality had already significantly deteriorated in the Mombasa Port region (Earth Matters Consulting, 2006).

Chlorophyll

Regionally, the WIO experienced generally decreasing levels of chlorophyll-a until 2014, with significant seasonal variability (UNEP, 2015). In Mombasa, chlorophyll-a levels, as measured by CHL1 in this study, increases dramatically in concentration from 2001 to 2002, after which the chlorophyll levels plateau and remain at relatively high values in comparison to 2000. A heavily polluting municipal waste site was decommissioned in 2002, possibly resulting in run-off of surface pollution impacting the water quality at the entrance of the estuary (Earth Matters Consulting, 2006). Most locations peak levels of CHL1 are recorded in 2007, particularly at P01, which aligns with the start of construction for the new container terminal modernisation project and sand harvesting nearby Shelly Beach (Kenyan Ports Authority, 2012).

P02 and P04 see significant drop in chlorophyll concentration immediately following 2011, however a general increasing trend can be seen from 2013 through to 2019, showing a positive correlation with increased cargo movement and port development within Mombasa. 2020 sees a decline in chlorophyll levels at all locations with available data, which may be a result of the COVID-19 implications on sea cargo transport logistics. Chlorophyll levels at P03 and P05 are typically more stable and lower than those at other locations. Data gaps for CHL1 at P01 are significant during this time period and thus further study is needed to assess the changes in the later half of this study (from 2012 onwards). This coincides with the rapid increase in port development following 2011 and plays an important role in assessing the impacts the port has had on Chlorophyll-a levels adjacent to the immediate port area.

Total Suspended Matter

TSM within the Port Reitz creek is heavily influenced by riverine and coastal watershed discharge, which includes runoff from the town and nearby agricultural areas (Earth Matters Consulting, 2006). TSM levels at P01 show increased variability over time than at all other locations, which may be attributed to the inner estuary environment with increased sediment load and shallower depths whereby tidal currents can disturb bottom sediments (Earth Matters Consulting, 2006). Despite the variability, there is an obvious increasing trend of TSM from 2003 to 2012, likely resulting from a combination of both increased port activity and a significant change in land use characteristics over that time.

Levels of TSM at P02 and P04 also remain relatively consistent across the decade, but at significantly higher levels than P03 and P05. This can be spatially attributed to their location within (P02) or closer to (P04) estuary systems. TSM levels at P02 and P04 see an increase in 2012, whereby they are higher than those recorded at P01, which is possibly a result of localised dredging nearby during this time.

In-situ water samples taken nearby P05 by *Earth Matters Consulting* (2006) returned very similar levels of TSM levels (<0.4g/m3), validating the spatial analysis results obtained in this study. Significant limitations of this study arose from data gaps and a distinct lack of available data from 2012 onwards for TSM. Significant excavation works as a result of the construction of the container terminal from 2011 onwards would have caused elevated TSM within the water column at P01, which may have been considered as outlying data and removed during the data processing and algorithm by *GlobColour*. The inability to assess changes over time following the intensification of port use in Mombasa from 2011 highlights further work is needed in this area.

Turbidity

Similarly, to the other parameters, turbidity, as measured by KDPAR in this study, at P01 shows variable measurements and is consistently higher than at the other locations. This is in line with it being within the estuary in a typically more turbid area, which is heavily impacted by sediment dense run-off during the wet season (Earth Matters Consulting, 2006). Turbidity at P01 peaks in 2007, which aligns with high chlorophyll values during that time, and again in 2016.

Turbidity at P02, P03, P04 and P05 peak in 2002, which is in line with chlorophyll results, and possibly attributed to the closure of a local heavily polluting waste site. Following this, a general decreasing trend, or reduction in turbidity can be seen until 2009. Chlorophyll and TSM also remain relatively stable during this time, which may be attributed to stability of port operations and development in the 2000s. Turbidity increases consistently following 2011, which coincides with the introduction of dredging and construction of the MPDP. Many of the point locations are within the sand harvesting area, which was considered to have only short-term impacts on turbidity in the region, however through continued development may have resulted in cumulative impacts. Overall, the results indicate there is a slight increasing trend in both chlorophyll and turbidity throughout the 2010's, which coincides with increased development at Mombasa Port. It is therefore highly likely that this trend can be attributed to the port and associated coastal development.

Limitations

It is difficult to assess general trends in water quality with the data used in this study. Significant limitations occurred as a result of very low resolution grid cells (4km), which reduced capability to filter out noise. There were distinct and many data gaps and consideration must be taken for the merging techniques and algorithms used to create the data on *GlobColour* (ACRI-ST GlobColour, 2020). Finally, the distinct lack of available in-situ water quality data in published literature resulted in the inability to validate spatial analysis results. Using a different, or multiple data source would be recommended to improve the results of this study, as well as comparison with other areas of the WIO region that are undergoing intensification of coastal developments.

6.2 LULC Discussion

LULC was assessed in order to quantify the rate of change of urban and coastal developments at Mombasa, to identify stresses and strains on the WIO natural environment and understand the change between different land-use types as a result of ongoing population growth in the region. The changes between different land-use types in Mombasa over the study period are predicted to be similar across the entire WIO region, or likely to occur in the near-future with continued population growth and increasing economic development.

Built Up Areas

Built up areas are those with human-made infrastructure, such as factories, housing or other commercial buildings. In the year 2000, built up areas accounted for 38.24km2 of the sampled area; in 2020 the built up area reached a total of 70.64km2, indicating there has been an 84% increase in urban areas over the 20 year sample period.

In 2004, built up areas accounted for 40.22km2 of the total area; by 2005 this had increased to 76.85km2. This is an increase of 91% in the built up class and represents a 124% increase on the average annual change of built up over the 2000-2020 time period. The majority (almost 80%) of the change in 2004 was sparse vegetation becoming built up areas.

In the year 2007 built up areas accounted for 53.29km2 of the total area, which increased to 93.76km2 by 2008. This represents over 75% increase in built up areas and a 151% increase on the average annual change of built up over the 2000-2020 time period of the study. Sparse vegetation (39%) and agricultural land (32%) had the largest loss to built up areas during the 2007-2008 time period.

Part of the original built up area in 2000 became other land use classes over that time (<40%), with the largest being to Bare soil (9.10km2) over the 20 year period. built up areas have experienced a significant net gain over the study period. The years 2004-2005 and 2007-2008 had experienced the most rapid development within this class.

Bare Soil

Bare soil areas are those which have no floral life present. In the year 2000, bare soil made up 13.08km2 of the sampled area; in 2020 bare soils accounted for 16.73km2 of the area, which is an increase of 27%. Only 1.97km2 - or 15% - of the original bare soils from the year 2000 was present in the year 2020. Bare soil that was lost became mostly sparse vegetation, forest and built up areas; however bare soil experienced a net gain over the study period. The years 2018-2019 experienced a large increase, whilst the years 2019-2020 had experienced a large decrease.

In 2018, bare soil accounted for 11.69km2 of the total area; in 2019 this increased to 35.34km2 which is an increase of 202%. Agricultural land (59%) and sparse vegetation (26%) had the most loss to bare soil during the 2018-2019 time period. In 2019, bare soil had accounted for 35.34km2 of the total area and in 2020 this had decreased to 16.73km2, which is a decrease of 53%. Agricultural land (46%), sparse vegetation (30%) and built up areas (20%) are the classes that accounted for bare soil loss during the 2019-2020 time period.

Sparse Vegetation

Sparse vegetation accounts for areas where floral life covers 10-50% of the surface area. In the year 2000, sparse vegetation totalled 150.76km2 of the sampled area; in 2020 the sparse vegetation amounted to 86.60km2, a decrease of 42%. Less than 40% of the original sparse vegetation was still present in 2020. Sparse vegetation was lost mostly to built up (30.43km2) and agriculture (47.81km2) and experienced a net loss over the study period. The most significant decreases occurred in 2006-2007 and 2017-2018 . In 2006 the total sparse vegetation decreased by 55.82%, mostly to built up areas. In 2017 the total sparse vegetation decreased by 53.32%, mostly to built up areas.

Forest

A forest is defined as an area covered with floral life and includes undergrowth. In the year 2000, forests had accounted for 17.21km2 of the sampled area; in 2020 the forest had amounted to 16.13km2 which is a decrease of 6%. Only 5.99km2 or 34.81% of the original forest coverage was still present in the year 2020. Forests were lost mostly to agriculture and bare soil and experienced a net loss over the study period. It appears that from 2006 to 2007 there was a large increase in forested land, however this was reversed in 2007 to 2008, when it was completely lost.

In 2006 the total forest land accounted for 7.04km2 and in 2007 this had increased to 26.14km2, an increase of 271%. This is a 158% increase from the average rate of change of forest over the 2000-2020 period. The majority of the increase was from sparse vegetation (56%). In the year 2007 forest lands decreased by 78%, mostly to sparse vegetation followed by built up areas.

Agriculture

Agricultural land is land that is used for the production of animal or plant products. In the year 2000, agricultural land accounted for 58.73km2 of the sampled area; in 2020 the agricultural land had amounted to 90.79km2 which is an increase of 55%. The majority of decreases in agricultural lands was to bare soils, sparse vegetation and forest. Agricultural land experienced a net gain over the study period, with the years 2006-2007 and 2017-2018 experiencing large increases in agricultural land.

In 2006 agricultural land accounted for 10.47km2 of the total area; in 2007 this increased to 98.84km2, which is an increase of 844%. This increase was a result of mostly sparse vegetation (80%) being turned into agricultural land as a result of increased population pressures on Mombasa. Similarly, in 2017 agricultural land increased by 344%, mostly from sparse vegetation (69%).

Water Bodies

Water bodies refer to any significant level of water on the surface of the planet. In the year 2000 water bodies accounted for 11.54km2 of the sampled area; in 2020 the water bodies had amounted to 17.02km2, which is an increase of 47%. Only 6.07km2 or 52% of the original water bodies were still present in the year 2020, with some areas being lost to mangroves and built up areas. Water bodies experienced a net gain over the study period, at relatively consistent annual levels.

Mangroves

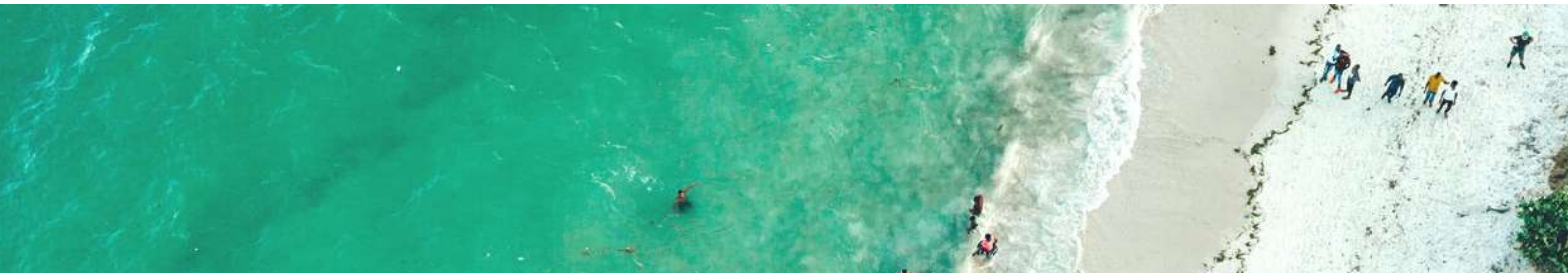
A mangrove is a shrub or small tree which tends to grow on coastal saline water. In the year 2000 Mangroves accounted for 37.82km2 of the sampled area; in 2020 the mangroves had amounted to 29.46km2 which is a decrease of 22%. Only 26.76km2 or 37% of the original mangrove area is still present in the year 2020. Mangroves had a loss of 3.2km2 to bare soils, sparse vegetation and forests, 1.61km2 lost to built up, 0.69km2 lost to agricultural lands and 5.54km2 lost to water bodies. This means that the remaining 2.70km2 had been gained from different classes throughout the study period. Mangroves have experienced a net loss over the study period.

Mangroves-Built up changes at an average rate of -1.06km2 per year, with the years 2002-2003 (-3.73km2) and 2007-2008 (-4.24km2) being above average losses. Mangroves to bare soils change at an average rate of -0.12km2, with no years being significantly above the average mark. Mangroves to sparse forest changes at an average rate of -1.44km2 with 2001-2002 (4.53km2), 2002-2003 (3.36km2) and 2008-2009 (5.08km2) considered above average.

Mangroves-forests changes at an average rate of -0.57km2 per year with no years being significantly above the average mark. Mangroves to agriculture change at an average rate of 0.23km2 per year with no years being significantly above the average . Mangroves to water bodies changes at an average rate of -2.55km2 per year with 2005-2005 (3.38km2) and 2007-2008 (4.99km2) being above average losses. Mangroves retain 29.77km2 of space per year with a steady decrease as the time period shifts closer to 2020.

Drivers of Land Use Change: The Anthropocene

"Population and poverty" drive deforestation as a result of unsustainable agricultural practices (Rowcroft, 2008). In the Mombasa region there have been large shifts away from sparse vegetation areas in favor of agricultural lands; this trend of sparse vegetation loss could be an indication of poor planning and could be considered less than optimal for agricultural and environmental purposes. Population growth is a driver of deforestation (Rowcroft, 2008). Population increase in Mombasa region have largely determined the rise and fall of certain land uses, with purposes that serve human interests (housing, workspaces and food) generally being predominant.



Kassa et al. (2016) also explain that resettlement within Africa is also a driver for land use change, specific towards agroforestry changes. Many people shift away from drought prone lands towards coastal regions in order to live a better life, this also adds to the increasing population which is being centered towards a specific area. This change in population also means that agricultural systems and housing systems need to keep up with the population change.

Mangrove loss means the loss of an invaluable ecosystem which support the ecosystem by providing natural habitats to aquatic animals including fish and birds, helping build solid soil foundations and help stop rapid coastal degradation. Chowdhury et al. (2017) explains that losses of mangroves are often linked back to agricultural and infrastructural increases. This links back to the rapid population increase and the translated stress onto the ecosystem.

Overall, As classes like Builtup and agriculture increase other classes like mangroves, sparse forests and forests decrease. Bare soil, Sparse forests and forests often form a close relationship to one another with change as often they are apart of natural progression/declining chains.

7.

CONCLUDING STATEMENT

7.1 Conclusion

The impact that port development will have on the WIO region in the coming decades cannot be understated. It will provide significant economic benefits, and will go a long way to promoting prosperity in the region. However, with development in marine areas come potential social and environmental consequences. Environmentally neglectful development in coastal regions has the potential to damage ecosystems beyond repair. These are the same ecosystems that support livelihoods in the form of tourism operators, fisheries, hospitality businesses, and many more smaller operations. Despite the broader economic benefits that come from port development, localised microbusinesses are still an important consideration and must not be discounted when planning for port developments.

The three key findings from the analysis undertaken highlight the need to have appropriate environmental checks in place when planning port development:

1. Increased Chlorophyll and KDPAR levels over the period as a result of the container modernisation project, potentially affecting fragile ecosystems around Mombasa Port.
2. Decreased natural capital in land use as a result of an increase in agricultural land and built up urban areas, potentially causing a flow on effect of environmental issues relating to habitat coverage and waste.
3. The intersection of terrestrial and marine ecosystems also suffering with a decline in mangrove cover, affecting marine processes and habitat availability.

Within the LULC sphere there is a shift in how land is utilised and this tends to be in accordance with anthropogenic factors such as population and poverty. As discussed, as population rises so too does the need to provide not only infrastructure to the population but also a need to provide a source of food and other resources. It can be seen that as built up areas and agricultural lands rise there is a loss of sparse forests, bare soils and forests, this is because those lands are being targeted as the ones which change in order to support the population. Further, Mangroves show a steady decline as water bodies tend to rise: this could be an indication of poor water quality which is steadily killing off the mangroves. Overall, as the population in the WIO region continues to rise so too does the decline of certain land types and better planning towards how these spaces are utilised will be key in order to maintain ecological stability within the region.

This analysis at Mombasa Port can be applied more broadly across the WIO region. As port development at Lamu begins to upscale and move towards it's current vision of 32 berths from 29, the water quality and LULC data analysed in this report serves as a precautionary tale that ecological assets are at risk unless properly managed or integrated into early planning. This is relevant across all future port development.

The broader implications of this are that as development continues in the region, environmental planning and mitigation become even more critical. Historically, planning seemed to focus mainly on services, operation and management and physical infrastructure of port development, with limited thought given to the natural infrastructure, or the natural environment (Taljaard, et al., 2021). With growth set to explode in the region it is timely to begin to integrate several theoretical concepts into practice to maintain best practice environmental management moving forward.

The process of port development takes years and decade to plan and implement. From site selection, through to master planning and design, to construction, operations and monitoring, it requires a significant amount of human, natural, and financial capital. By looking to integrate into every level of planning, nature can begin to play a more purposeful role in the WIO region's development and benefit a wider circle of groups.

Taljaard et al. (2021) suggests this takes many forms, such as the below:

Raising the Environments Profile.
When planning for port development (in physical infrastructure and operations), ensure that the environment is tangibly represented in all relevant planning documents.

Building With Nature.
Rather than seeing the built environment and nature as separate entities, build so that they can co-exist in the same space without detractors for either.

Appreciation of Co-Benefits of Natural Capital.
Acknowledge where there are benefits when the environment is considered. Mombasa Port is an excellent example of this; with a thriving tourism sector running along Shelly Beach and the Old Fort district, when the natural environment is healthy and in abundance, this increases the appeal of these economic activities.

With this in mind, there is significant opportunity for development in the WIO region to further integrate environmental planning principles into practice; the region is far from mature in terms of development, with a significant portion of growth still to happen. Mature, developed regions around the world are unable to integrate natural capital into coastal infrastructure at the scale that the WIO ports can; this outlook can therefore be turned into something largely positive for the region as the benefits of having a healthly and abundant environment existing alongside port development can be realised to its full extent.

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APPENDIX 1:
WATER QUALITY DATA

Year	Average Annual CHL1 (mg/m^3)				
	P01	P02	P03	P04	P05
2000	-	0.119	0.142	0.146	0.137
2001	-	0.195	0.259	0.167	0.172
2002	1.273	0.958	0.628	0.923	0.503
2003	6.931	0.825	0.512	0.822	0.495
2004	12.658	0.787	0.459	0.785	0.354
2005	-	0.731	0.355	0.725	0.326
2006	-	0.784	0.528	0.781	0.387
2007	30.221	0.994	0.538	0.991	0.426
2008	7.562	0.716	0.328	0.712	0.268
2009	6.355	0.746	0.359	0.744	0.296
2010	1.474	0.949	0.370	0.946	0.352
2011	-	0.682	0.294	0.680	0.279
2012	0.609	0.419	0.305	0.418	0.301
2013	-	0.270	0.256	0.270	0.251
2014	-	0.323	0.257	0.322	0.294
2015	-	0.256	0.226	0.256	0.222
2016	-	0.331	0.271	0.329	0.289
2017	-	0.393	0.357	0.404	0.347
2018	-	0.351	0.260	0.350	0.311
2019	-	0.402	0.294	0.401	0.372
2020	-	0.348	0.241	0.348	0.282

Year	Average Annual TSM (g/m^3)				
	P01	P02	P03	P04	P05
2002	1.897	2.735	0.570	3.132	0.377
2003	1.934	3.185	0.522	3.177	0.481
2004	2.707	2.689	0.653	2.682	0.403
2005	2.927	2.531	0.737	2.523	0.312
2006	4.477	2.653	0.433	2.645	0.366
2007	2.701	2.435	0.592	2.428	0.362
2008	5.204	2.415	0.559	2.409	0.263
2009	4.345	2.540	0.591	2.533	0.231
2010	3.704	2.678	0.429	2.672	0.271
2011	5.288	2.372	0.515	2.364	0.414
2012	2.833	3.027	0.541	3.019	0.447

Year	Average Annual KDPAR (m^{-1})				
	P01	P02	P03	P04	P05
2000	-	0.105	0.100	0.105	0.095
2001	-	0.104	0.099	0.104	0.095
2002	0.293	0.110	0.100	0.110	0.098
2003	0.476	0.105	0.097	0.105	0.095
2004	0.400	0.096	0.092	0.096	0.088
2005	0.385	0.096	0.089	0.095	0.086
2006	0.458	0.100	0.094	0.100	0.089
2007	0.551	0.097	0.094	0.097	0.088
2008	0.386	0.091	0.085	0.091	0.081
2009	0.413	0.089	0.086	0.089	0.080
2010	0.307	0.097	0.092	0.097	0.087
2011	0.402	0.089	0.082	0.089	0.079
2012	0.305	0.092	0.086	0.092	0.084
2013	0.353	0.091	0.085	0.091	0.082
2014	0.373	0.093	0.088	0.093	0.084
2015	0.332	0.091	0.085	0.091	0.082
2016	0.569	0.095	0.088	0.095	0.085
2017	0.478	0.098	0.091	0.098	0.088
2018	0.324	0.094	0.091	0.093	0.084
2019	0.423	0.096	0.089	0.096	0.086
2020	0.378	0.096	0.089	0.096	0.087