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Port Access in the Lake Tanganyika: Key Challenges and Recommendations

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Water Global Practice
Africa Region

Acronyms

DRC	Democratic Republic of Congo
LTA	Lake Tanganyika Authority
m.a.s.l.	meters above sea level

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1. INTRODUCTION

In 2016, the Republic Democratic of Congo (RDC) and Tanzania requested World Bank support for the implementation of the Lukuga project, a dam on the sole outlet of Lake Tanganyika, whose purpose was to stabilize the Lake water level in order to secure ships access to its main ports. It was indeed perceived that decreasing water depths in the ports and their access channels during the low water-level season and dry years was hindering transport and trade in the Central and Eastern Africa corridor to which Lake Tanganyika is a critical element.

The present study is a response to this request. Its main objective is to determine the relevance of the Lukuga project by assessing the ships difficulties in accessing the main ports on the Lake, characterizing impact on transport and trade, identifying the main factors hindering access to ports and proposing a combination of measures to mitigate those factors. The audience are the decision makers in the riparian countries of the Lake, specially DRC and Tanzania who initiated this request, and the Lake Tanganyika Authority.

The study was carried out by a multidisciplinary team of experts including Pedro Figueira and Reynaldo Bench. The Bank team was led by Aleix Serrat-Capdevila (Senior Water Resources Management Specialist, GWASO/GWAGP), and composed of Marie-Laure Lajaunie (Lead Water Resources Management Specialist, GWA07) and Laura Bonzanigo (Water Resources Management Specialist, GWA07), working under the guidance of Alexander Bakalian (Practice Manager, GWA07). We wish to thank several colleagues at the World Bank for providing valuable comments, including Sanjay Pahuja (Lead Water Resources Specialist, GWA03), Abedalrazq F. Khalil (Senior Water Resources Specialist, GWA02), Nora Nora Weisskopf (Transport Analyst, GTI02), Andre A Bald (Program Leader, AFCE1), Kiyoung Park (Senior Hydropower Specialist, GWAGP), Alexander Bakalian (Practice Manager, GWA07), Laurent Debroux (Program Leader, GWA07) and Ahmadou Moustapha Ndiaye (Country Director, AFCC2). We also wish to express our appreciation for the excellent cooperation from the Comité Technique de Suivi du Projet Lukuga (Tanzania, DRC), including Mr. Anatole Massini (CTSM Lukuga coordinator), Mr. Max Matanji Gapay (Ministere de l'Energie et des Ressources Hydrauliques) from D.R. Congo who accompanied the mission to Tanzania and Burundi, Mr. Sylvester Matemu (Ministry of Water and Irrigation) in Tanzania, and the cooperation from the Lake Tanganyika Authority, including Mr. Gabriel Hakizimana (LTA) in Burundi. A draft version of the study was reviewed and discussed by the RDC and Tanzanian authorities in May 2017, and the final report was submitted to the Governments in July 2017. The French version of the study is entitled "*Accès aux Ports du Lac Tanganyika, Principaux Défis et Recommandations*".

The study followed a mixed methods approach, combining historical data records, remote sensing estimates, satellite images, on-site measurements and data collection, and oral narratives. The team used historical lake level records, dating back to the colonial times with varying quality over the years. It combined these records with more detailed remote sensing lake level estimates of the past twenty-five years and recent local bathymetry when available (i.e., in the port of Kalundu), as well as on-site gauge readings and oral narratives during a mission. This enabled a long-term perspective of the variability range of lake levels. To fully understand the dynamics of wind and wave currents, sediment transport and deposition in the lake and in the ports, the team used sequences of *Google Earth* images over the last sixteen years. Finally, the team interviewed a range of local actors including port authorities, government representatives and experts on port problems, shipping and navigational issues, and dredging in the ports.

The report starts with a brief presentation of the Lake Tanganyika in the context of the regional trade and transport corridor. Chapter 2 assesses the difficulties for the ships to access the main ports in the Lake and their consequences on transport and trade. It also identifies the factors hindering access. Chapter 3 discusses the relevance of the proposed dam on the Lukuga river. Chapter 4 presents a series of measures aimed at ensuring ship access to the ports. Chapter 5 provides a summary of the main conclusions.

The Lake Tanganyika

With a surface area of 32,900 km^2 and a maximum depth of 1.4 km, Lake Tanganyika is the second largest lake in Africa by surface and the second largest in the World by volume and depth. Its hydrographic basin of 263,000 km^2 is shared between five countries (DRC, Tanzania, Zambia, Burundi, Rwanda), of which all but Rwanda also share its coastline of 1,900 km^2. Millions of people depend on the Lake for transport, food security and as a source of livelihood. Lake Tanganyika is also a global hotspot for biodiversity. It is a critical element of the transport and trade corridor between central and east Africa. People and cargo are transported between the Lake's four major ports (Kalemie in DRC, Kigoma in Tanzania, Bujumbura in Burundi and Mpulungu in Zambia) and hundreds smaller ports. Ninety percent of Burundi's exports and 70% of its imports are traded over the lake. Estimates suggest that Lake Tanganyika harbors at least 1500 species out of which approximately 600 are currently considered endemic to the lake. The Lake has some of the largest freshwater fisheries on the African continent, on which depends the livelihood of its shoreline communities and the food security of millions of people living in the region. Recognizing the value of Lake Tanganyika for biodiversity, food security, transport and trade, its four riparian States signed in 2003 and ratified in 2008 the international convention for the sustainable management of the Lake Tanganyika. Proving the legal framework for the management of the Lake and its resources, the Convention specifically addresses navigation and sedimentation, thematic particularly relevant to the current study.

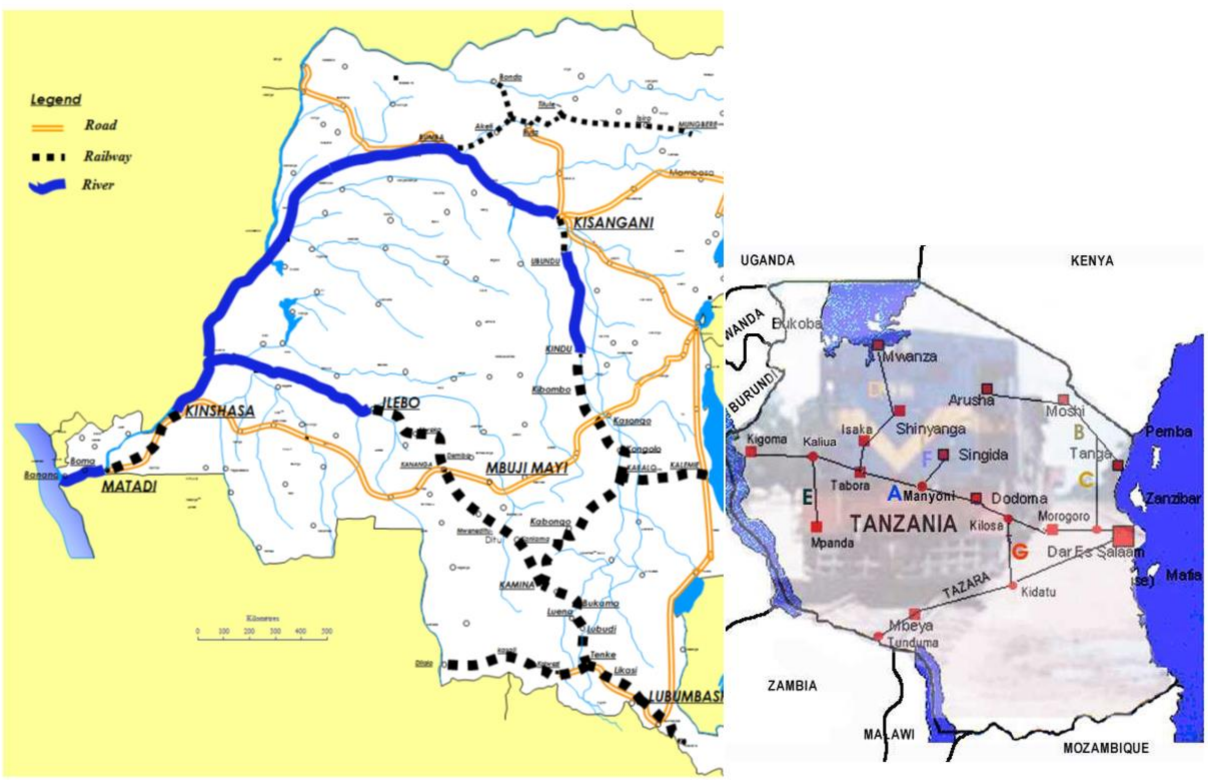
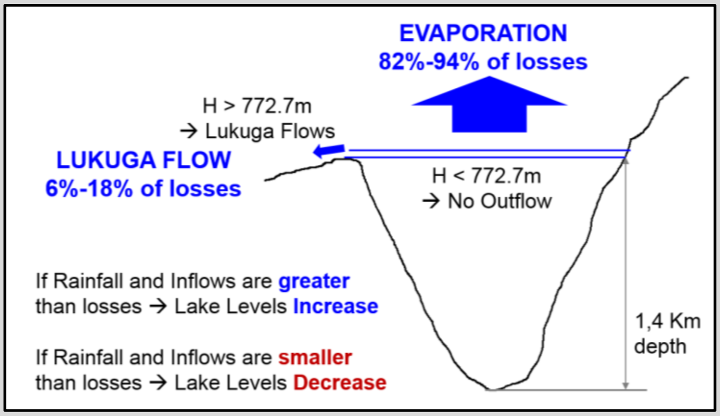


Figure 1: Transport networks to the East and West of Lake Tanganyika, connecting Tanzania and the interior of Congo, Burundi and Zambia.

The Functioning of Lake Tanganyika and the Lukuga River

Lake Tanganyika was a closed basin before 1878, until high water levels overflowed and eroded the Lukuga outlet to its current rock sill at the elevation of 772.7 meters (a.m.s.l.) at the mouth of the river, with humans later widening its mouth in 1941 to increase outflow capacity. The flows of the Lukuga represent from 6 to 18% of the losses of the lake, the rest being due to evaporation from the lake's great surface (see section 2.3.1 for a detailed description of the water balance). The flows of the Lukuga depend on the lake's water levels: the higher the levels the higher the Lukuga flows. When Lake levels get close to the elevation of the Lukuga outlet, the outflows become very small and the Lukuga River stops flowing if the lake level goes below the sill of the Lukuga.



2. THE ISSUE: SHIP ACCESS TO THE PORTS

2.1. Problem description and current situation

It was reported through oral narratives that the lake's water level dropped by about 1 or 1.5 meters during the last decades, and that episodes had occurred during which ships could not access the ports due to shallow water conditions and insufficient depth. In those conditions, ships had to anchor at a distance, outside the port, and load and unload cargo via smaller boats to the shore. These events occurred during the low water season at the end of the dry season.

These episodes were not documented in written records and the number of ships and cargo that encountered such difficulties could not be quantified, or the additional costs of loading and unloading quantified. There was no evidence or narratives of shipping transport or volume of cargo being cancelled, but reports of having to load and unload the ships, anchored outside the port, using small boats.

At the time of the visit during the last week of October 2016, the lake level was of 774.25 m a.m.s.l., verified in the scale of the Bujumbura port (Figure 2.1). At that level and after recent dredging, the ports of Bujumbura and Kigoma offer a reported depth of 4 meters, with good operations and no docking problems. Similar depths are reported for the ports of Uvira and Kalemie, but difficult docking conditions are reported for large ships. This is due to narrow access channels, rock outcrops (the cause of shipwrecks) and lack of navigational aides.

Figure 2.1: Lake Tanganyika Level as reported by the scale of the port of Bujumbura (October 24th of 2016).

Detailed information on shipping and navigation in the lake, the current status of its main ports, current fleets and volume of cargo and passengers over the lake can be found in the *ANNEX - Ports & Transport information*.

2.3 Causes of the problem

Two main factors were identified as causing the depth constraints preventing ships from docking in the Lake's Ports: (1) seasonal and annual variations of lake levels, and (2) sedimentation in the ports from neighboring contributing rivers. This chapter explores the dynamics of these two factors in detail, to inform potential solutions to the problem.

2.3.1 Lake Level Variations

Lake level variations are both seasonal and interannual. Seasonal water level variations in Lake Tanganyika are due to the marked seasonality of rainfall and average 70 to 80cm depending on the year, with highest water levels at the end of the rainy season (October – May) and lowest water levels at the end of the dry season in September/October. The inter-annual variation of lake levels is due to the variability of annual rainfall, depending on wetter or dryer years. The changes in water volume of the lake, and thus lake levels, can be expressed as in the equation below. In wetter years, when inflows are greater than outflows, the change in volume is positive and lake levels increase; in dryer years, lake levels decrease. As is common in natural processes, occasional series of wet years stacked together can cause an increasing short-term trend, and a series of dry years can cause a decreasing short-term trend (as seen in Figure 2.2).

Lake Volume Changes = Inflows (Rainfall + Streamflows) – Outflows (Evaporation + Lukuga Outflows)

The levels variations are a function of Inflows and Outflows to the Lake, with annual evaporation representing in average over 82% to 94% of the lake's outflows, and the flow through the Lukuga amounting to the remaining 6% to 18% approximately. Several estimates exist of the water balance of the lake but observational data on the different components is limited. Inputs to the Lake are direct rainfall on the Lake's surface, estimated at about 900 to 1,000 mm/y, and runoff from its hydrologic basin, roughly estimated to contribute from 430 to 950 mm/y, making total inputs range from 1,330 to 2,000 mm/y. Evaporation from the Lake surface is an estimated 1,500 to 1,700 mm/y. The Lukuga is the only river flowing out of the lake and its flow magnitude depends on the level of the lake. If the lake level drops below the riverbed of the Lukuga, currently at 772.7m[1] (a.m.s.l.) the flow is zero. If the level is above that threshold (as it has been in the last 100 years), average annual outflows have been estimated at 83 to 365 mm/y of lake height, equivalent to average annual flow of 86 to 380 m3/s (with a reported maximum flow of 1,377 m3/s in May of 1970 due to levels above 776.5 m). The current rating curve (relating height to flow) of the Lukuga near Lake Tanganyika is unknown and thus there are no current estimates of its flow.

Historically, lake levels have oscillated between 773 and 776 m (a.m.s.l.), and there is no evidence of long-term decreasing trends. Figure 2.2 shows lake level oscillations of the last 25 years as seen by satellite observations and referenced at the scale of Bujumbura during the time of visit (October 24, 2016), and other elevations of interest: the Lukuga riverbed, port surfaces, and minimum bottom elevation in ports for safe operation in dry years.

[1] Devroey (1938, 1949) refer to a rock layer at the riverbed outlet at 772.7m in 1878. Reliable recent measurements are lacking.

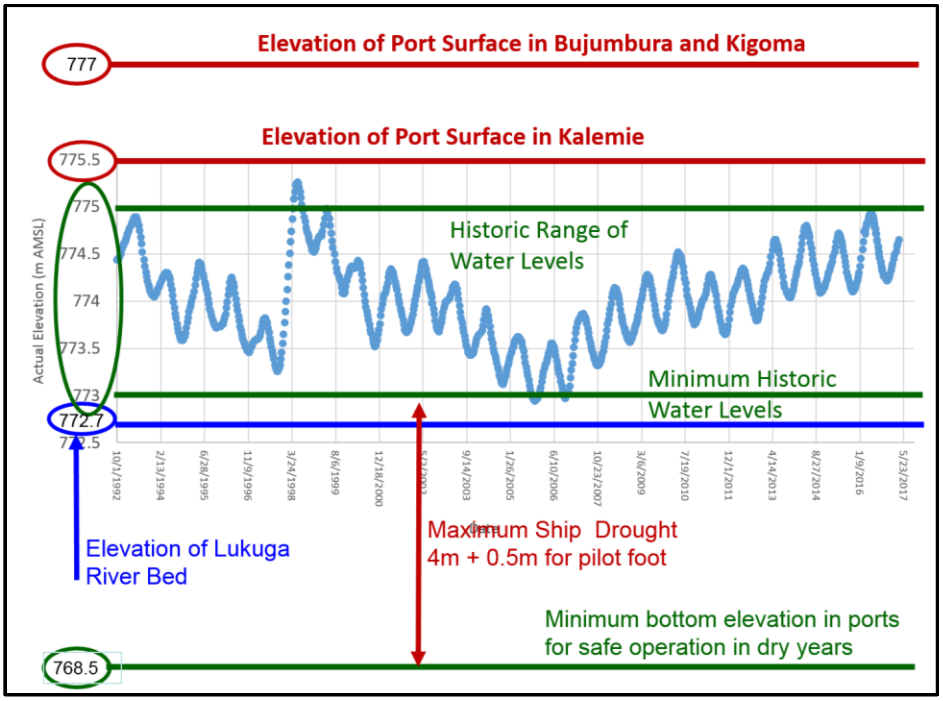


Figure 2.2: Lake levels, the Lukuga riverbed and other elevations of interest.

2.3.1 Sedimentation in Ports

Sedimentation in access areas and port basins is one of the problems that the ports of Lake Tanganyika must deal with. Most of the sediments that arrive to those areas are transported along the coastline by currents generated by wind, and sub-sequent wave breaking. Waves put sediments in suspension in the wave breaking zone, and create a current that transports sediments along the shore. When these sediments arrive to areas where the current velocities decrease significantly or become zero, they fall to the bottom, creating sediment accumulation zones. This is the case of port entrances where sediment banks can grow up, or of sudden direction changes in coastline where sand spits can form.

The winds blowing along the water surface generate currents in the blowing direction, as well as waves. These currents are, in general, weak, but they have the capacity to transport the fine sediments that are suspended in the water. The persistence of the phenomenon may induce morphological changes at the lake bottom and banks. The joint occurrence of wind and wave currents may create the conditions for strengthening the effects of sediment transport and deposition. Although in the lake these phenomena do have small intensity, its persistence generates visible effects.

Figure 2.3 shows the 10 year evolution of a sand spit in Burundi’s coast. Although that is not a rapid evolution, it shows that the persistence of the wave action is sufficient for driving the evolution of local features in the shores of Lake Tanganyika.

Figure 2.3 – Evolution of a sand spit at about 22km south of Port of Bujumbura (growth of 150m in 10y)

An analysis was made for the ports of Bujumbura, Kalemie, Uvira and Kigoma, to provide an overview of the sediment dynamics in their vicinity. This analysis was done using images from Google Earth for different dates, and integrating information obtained in discussions with port officers.

Port of Bujumbura (Burundi)

The Port of Bujumbura is very affected by sedimentation, as was confirmed during the site visit and observed in satellite images. The area adjacent to the North of the port, the delta of the Ntahangwa River, shows a strong evolution from 2002 to 2016, with an increase of more than 30 hectares due to sediment contributions from the river's watershed (Figure 2.4).

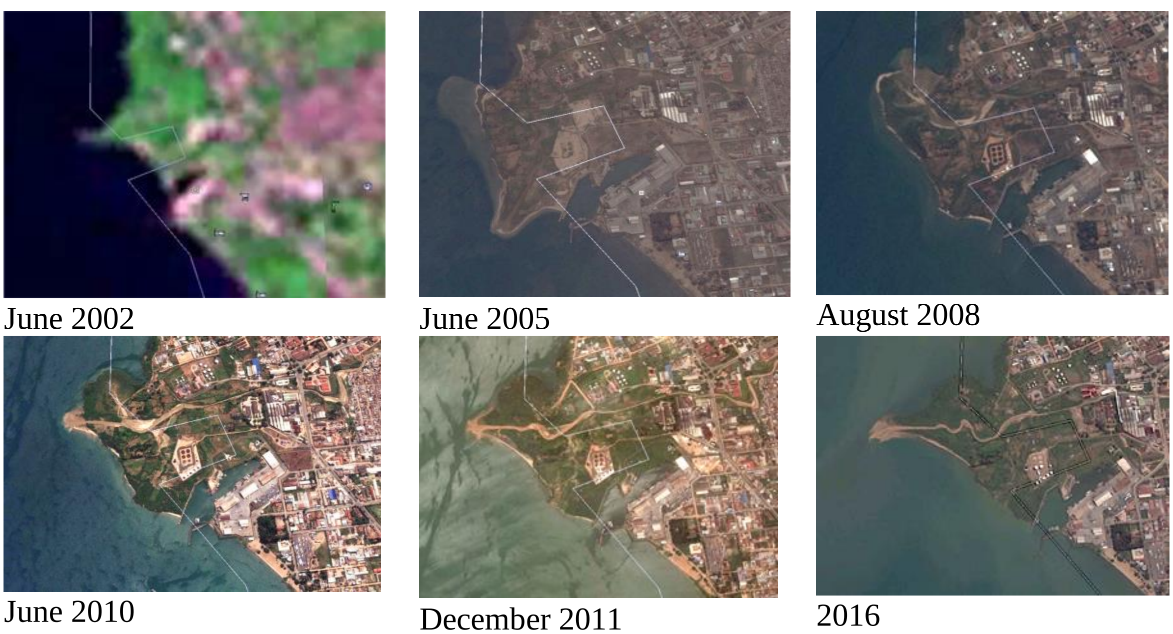


Figure 2.4 - Evolution of the Ntahangwa River area adjacent to the Port of Bujumbura.

Sediments in suspension in the lake’s water near the port were clearly visible, mainly brought by the Ntahangwa and Russizi rivers, and mobilized by wind currents and the action of waves along the shores. In this case, the wind blowing from the West, generates surface currents that push that water with sediments towards the port of Bujumbura.

In addition, there is an urban drainage collector coming from the city which drains into the inside of the port basin, bringing sediments directly into the port (Figure 2.5).

Figure 2.5: Aerial view of the urban drainage collector from the city directly draining into the port basin.

The Bujumbura port authorities and the Captain of the MV Liemba reported a strong influence of sedimentation in the port operation.

Port of Kigoma (Tanzania)

Local reports indicated that the main source of sediments discharged into the port basin, is an area of about 100 hectares, susceptible to erosion during rainfall and runoff. A more detailed analysis of Google Earth images shows that the catchment area of the Kigoma Bay is in the order of 1000 hectares. The sediments eroded from this entire watershed are the likely causes of significant rises in the port’s underwater topography, or port bottom, in certain areas. Local measurements in 2010 estimated a sediment fill of approximately 4m since previous or initial port depths (Rutagemwa 2010). As regular or periodic quantitative measurements and surveying capabilities are lacking, the need for bathymetric survey equipment is highlighted, as well as for sediment granulometric analysis. Local knowledge and past dredging statistics may be used in the meantime to estimate sedimentation rates and dredging needs.

Figure 2.6 - Port of Kigoma in 2010 (above) and 2016 (below)

Port of Kalemie (DRC)

Oral narratives during the field visit to the Lake, including accounts from Congolese sailors from Kalemie, at the port of Kigoma, the approaches to the port of Kalemie and the port entrance itself suffer of strong sedimentation, which significantly affects port operation. Many officers, including the Captain of the MV Liemba reported that water depths along the vicinity of the port breakwater are very small.

The Kalemie River reaches the Lake just to the south of the Kalemie port, adjoining its facilities and the railroad station. It drains a watershed that over the last decades lost its vegetative cover in a complete transformation from rural to urban, and which is an important source of sediments. Prevailing winds from the Southeast create waves which, when breaking near the shore put sediments in suspension in the water, and yield currents from south to north. The significant contribution of sediments from the Kalemie watershed, and the winds/waves from the South East, make the sediments travel the short distance along the coast and port breakwater, tending to sediment at its entrance. These processes can be seen very well in

Figure 2.7, where in year 2006 one can observe a small delta at the mouth of the Kalemie River, delta that was not there in year 2002. However, in 2009, the delta has been eroded by the wave action and the sediments transported north along the coast, most of which likely settled at the end of the breakwater and entrance of the port, as can be observed in the lower right image of the figure. This is a typical pattern of sedimentation in coastal ports with similar structures, as can also be seen in the port of Kalundu in Uvira.

Figure 2.7 – The port of Kalemie and the adjoining Kalemie River to the south. Note the Kalemie river delta in 2006, its disparition in 2009, and the accumulation of sediments along the breakwater and entrance of the port.

The Port of Kalemie is also located about three kilometres south of the Lukuga River mouth. The flow towards the river may also produce currents in that area of the lake that converge towards its mouth. This can be seen in the paths of fine brown sediments in suspension being transported towards the river (Figure 2.8).

Figure 2.8 – The Port of Kalemie and the mouth of the River Lukuga.

Port of Kalundu (DRC)

The port of Kalundu, being also on the western shore of the Lake, and subject to the waves arriving from the Southeast, has very similar sediment transport dynamics as the port of Kalemie. Sediments put in suspension by the wave breaking action in the shore are transported north by the current, and settle at the port entrance, at the end of the breakwater. A recent bathymetric survey (22/23 of April 2016) characterized the port bottom topography, displaying the areas of sediment accumulation along the breakwater and at the port entrance. In addition, a significant contribution of eroded sediments from the land has also been reported. A narrow and difficult access channel can be observed in Figure 2.9, displaying the bathymetric map produced after the survey.

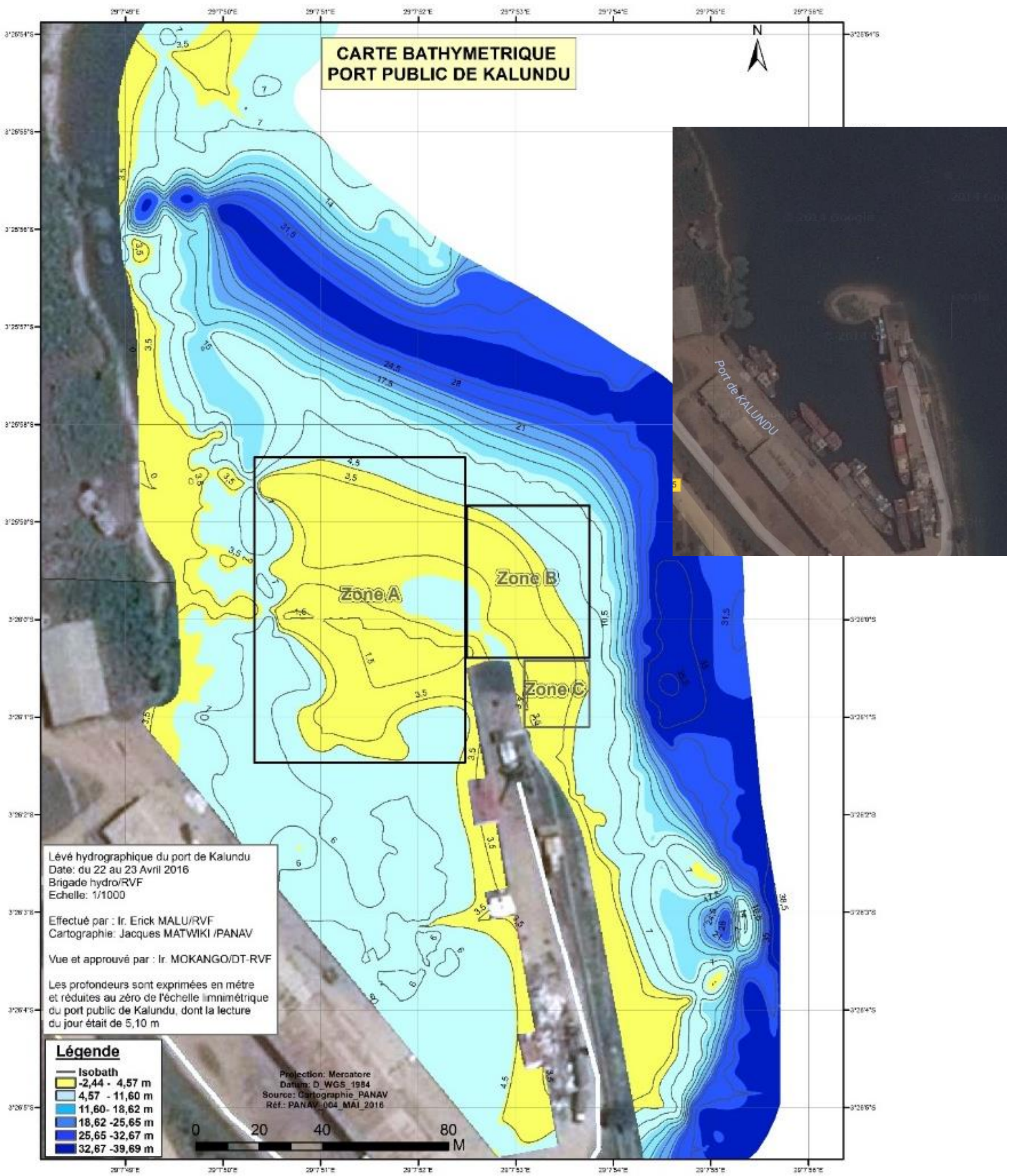


Figure 2.9 – Bathymetric map of the port of Kalundu near Uvira (DRC) showing the topography of the port bottom and water depth. A satellite image in the upper right is provided for comparison, with the caveat that the dates of the photograph may be quite older than that of the bathymetry, hence the differences in the shape of the sediments seen above water.

Summary of Sedimentation: sedimentation in ports is a natural and continuous process affecting all the ports of the lake. Rivers in the vicinity of the ports are the main source of sediments and the process is exacerbated by watershed degradation leading to increased erosion and sediment transport into the lake's shores. Sedimentation is a constant and cumulative process in time, thus very predictable and without uncertainty, which can be managed but it cannot be stopped. Ports require the constant removal of sediments to maintain water depth. The lack of proper maintenance dredging and sediment management is the main cause for the difficulties in accessing the ports due to small water depths.

3. IS THE LUKUGA DAM THE SOLUTION?

The historical variations of water level in Lake Tanganyika by themselves have not been the problem for ship access. In the last one hundred years, levels have oscillated between 773m and 776m (a.m.s.l), only descending below 773 m a handful of times during the dry season, including recently in 2005 and 2006. Given that the existing fleet requires 4.5m of water depth to operate and dock in the ports, and that initial port bottom design elevations were lower than 768.5 m (a.m.s.l), it can be concluded that lake levels in the dry season have only become an issue because of sedimentation. While nothing indicates a decreasing trend in lake levels, the bottom levels in ports have been increasing due to sedimentation and lack of regular dredging.

In addition, even if the variation in water levels was the main cause of the problem, the dam would not solve the problem, as evaporation is the main outflow and cannot be controlled. Annual evaporation over the lake averages over 1.7m. It, is relatively constant through the years and represents 82% of losses from the lake. The Lukuga outflows historically represent 18% of lake outflows, thus a Dam in the Lukuga would only regulate 18% of lake level changes. The other 82% of changes accounting for ET would be uncontrollable. Because rainfall is variable, the differences between rainfall and ET make the lake levels go up or down.

If lake **levels are low** (dry years), the outflow in the Lukuga is small and the dam would only regulate a very small percentage of losses. Even if these losses were avoided, lake levels would remain low because of the much larger magnitude of evaporation over the lake. In this case the dam loses relevance when it would be most needed. If a series of abnormally dry years were to occur, lake levels could eventually decrease below the Lukuga riverbed, even with a dam, due to evaporation losses.

If lake **levels are high** (wet years), the dam would increase flooding risk. Since the Lukuga represents such a small outlet for such a great lake, its capacity to drain and regulate the lake in case of high levels is limited, and as seen in previous historical episodes, flooding due to high lake levels can persist for quite some time even without the dam. Given the small gradient of the Lukuga River, a dam would certainly reduce the flow capacity of the Lukuga outlet during periods of high flows, effectively increasing the frequency and duration of flooding in the lakes shores, which is currently already a problem. This would occur without solving the sedimentation dynamics in the ports, which as mentioned previously are a continuous and ongoing coastal process affecting all ports anywhere in the world.

4. MAIN RECOMMENDATIONS

The present situation requires good sedimentation management, and a series of measures are proposed below to address this issue. The current level variations are within the range of the last one hundred years, and there is no evidence of a decreasing or increasing trend in lake levels. If in the future, levels decreased below their historical range, additional measures would be needed to move port operations to deeper areas. In addition, and based on the field visits, recommendations on navigation and port operation are also provided. Despite unavailability of data regarding shipping disruptions due to depth constraints, and of other variables, the nature of problems in the ports is well characterized and their causes are well established, based on the availability of lake level data, oral narratives, and satellite imagery. In this context, the following recommendations hold very strongly.

4.1. Sedimentation Management

Measures for sediment management range from dredging inside the ports, to intercepting sediments before they get to the ports or the lake, including coastal structures, sediment traps in washes and soil conservation across the watershed. The following recommendations are listed by order of priority:

Dredging in ports is obligatory and a system needs to be established enabling periodic dredging in all the lake's ports. Ports need to develop a dredging strategy based on how frequently dredging may be needed, the amount of sediments to be removed at each dredging event, and a safe location to dispose of the dredged sediments. An initial strategy can be developed based on historical knowledge of the ports, the loss of depth since port construction, past dredging events and recent bathymetric surveys.

Dredging equipment and financing need to be secured. Ports need access to dredging machineries, whether they are individually owned by a port or a country, or shared among the lake's ports (perhaps through the Lake Tanganyika Authority or similar). Similarly, the ports need to raise sufficient revenues for regular periodic dredging by improving their financial situation/revenues, or through better allocation of expenses. The balance would need to come from the government's budget. **Bathymetric survey capabilities** are needed for all the lake's ports, in parallel to a good dredging system and as part of a ports sediment management system. Both in terms of equipment and of human technical capacity, along with cartographic capacity. Current survey equipment allows for high resolution surveys made with acceptable costs, such as a multi-beam echo sounder which provides three-dimensional measures of sedimentation patterns and can guide dredging activities. It is important that these surveys are then used to produce nautical charts for navigation and for sediment and dredging studies, to inform future dredging and evaluate the benefits of other sediment management measures.

Dredging programs and sediment management measures are an integral part of port management and all ports anywhere require periodic maintenance dredging. Thus, the budgeting of dredging programs within port operations planning is essential. Past costs of dredging in Lake Tanganyika have been highly variable but in many cases higher than in most ports, mostly due to the lack of established systems and equipment. Dredging costs of between \$3 and \$7 per cubic meter are international seaport benchmarks. Dredging campaigns in some of the Lake's ports have exceed the above figures, judging from the total cost and the total volume of sediments dredged. If a dredging system was owned locally and professionally operated and maintained, the costs per cubic meter could likely be within that range. Also, experiences exist in many locations of performance-based dredging contracts, where the dredging operator is paid based on the volume of sediments dredged.

Also as a priority, two specific measures need to be taken. First, the course of the urban drainage collector leading directly into the basin of the Bujumbura port (and transporting sediments there) needs to be changed to reach the lake at a different location outside the port. Alternatively, the current path could be maintained, but works would be necessary to prevent the transport of sediments into the port basin (sediment traps or filters), but this option would entail maintenance challenges. Second, the neighboring area to the port of Kalundu (Uvira, DRC) has been reported to be a source of sediments that are drained directly into the port. Works should be done to protect the port basin and access channel from sediment sources in its immediate vicinity.

Coastal structures can be helpful in some cases, to significantly reduce the amount of sediments entering the ports and are cheaper to maintain. Periodic removal and emptying of sediments from coastal structures is much easier as it can be done from the land. Structures like groins and breakwaters can accumulate sediments as they travel along the coast, depending on the prevailing wind and wave direction (Figure 4.1). A hypothetical groin field south of the port of Kalemie is represented in Figure 4.2 between the mouth of the Kalemie River and the Port of Kalemie, to display how sediments could be captured and periodically removed before they travel to the port and settle at its entrance. The periodic removal of sediments from the coastal structures would best be done during the low water levels at the end of the dry season.

Figure 4.1: Illustration of groins (left) and breakwaters (right) as structures to retain sediments along the coast.

Figure 4.2: Illustration of how a hypothetic groin field in the shores of Kalemie can capture sediments from the Kalemie River and traveling along the coast, to prevent their accumulation at the entrance of Kalemie's port.

Sediment traps in key locations along rivers and washes **are a complementary measure** to reduce sediment loads transported into the lake and in the vicinity of ports. Periodic maintenance is required to empty the sediments from the traps, with the advantage that removing sediments from behind a sediment trap on land is much easier and less costly than dredging under the water surface. In addition, the sediments can easily be used for commercial purposes, such as construction or public works. These measures should be built as part of a broader watershed restoration and soil conservation efforts, and along with coastal structures, these are likely to significantly decrease the frequency of dredging.

Watershed soil conservation and restoration efforts, involving reforestation and erosion control, will yield **in the long-term** a range of benefits in addition to reducing sediment transport into the lake. A study would first need to identify and prioritize sediment source areas, what measures would be needed, and to identify the optimal designs and locations for interventions. Land degradation has been an increasing trend in Lake Tanganyika's basin in the last decades. Human communities have progressively cleared lands for agriculture, pastoral lands, and firewood, leading to a significant increase in soil erosion and sediment transport into the lake's shores. These activities are part of a broad spectrum of poor land use practices, pollution and environmental degradation, and a holistic watershed and environmental conservation approach is highly recommended, as on them depends the future sustainability of many economic and livelihood activities around the lake.

Watershed Management and Sediment Transport: Many examples exist of the benefits of watershed conservation, reforestation and sediment/soil erosion control. In the case of the Yellow River in China, watershed restoration and soil conservation efforts, combined with sediment trapping, resulted in an 80% reduction of sediments. Similarly, soil-conservation programs throughout the watershed of the Mississippi River reduced the supply of sediments significantly. These, combined with river stabilization works in the 1970s, made maintenance dredging requirements decline by nearly 95% (Khalil, 2015). Taking and integrative approach from the watershed, through the river, to the lake's shores, a *working with nature* approach can be adopted, investing in understanding well the natural dynamics and processes, to develop well-adapted solutions that will reduce the need for human maintenance and intervention in the future.

4.2. What to do if lake levels decrease in the future?

Currently, nothing indicates a long-term decreasing trend in the lake levels, as these have been within the range of historical variations.

While scientists agree that temperatures are and will continue to rise in the future, they are unable to predict trends in rainfall to a useful level, thus potential future lake level variations are impossible to predict. Climate variability is subject to seasonal and annual variability but also to inter-annual and multi-decadal natural variability, meaning that the climate in a certain region can shift to a wetter or dryer pattern for a large number of years, or a pattern of alternating wet years and dry years, potentially causing periods of high and low waters. While this natural variability is somewhat understood but very difficult to predict, the effects of man-made global warming will be super-imposed on top of natural variability and even more unpredictable.

If lake levels adopt a decreasing trend in the future, the dam would not be able to regulate them, as it could only slow them by 6 to 18%. Evaporation (82-94% of losses) would progressively lower water levels until they reach the elevation of the Lukuga river bed (772.7 m a.m.s.l.), at which the dam would become irrelevant.

In case lake levels decrease in the future, or they oscillate more than their historical range, with frequent periods of lower waters, ports will have to adapt their berthing structures to enable operations in deeper areas with lower water levels.

4.3. Additional recommendations: port functioning, shipping and navigation

Other factors observed during the field visits are also a reason for concern, in addition to water depth in the ports. These include the lack of navigational aids (charts, radios), the conditions of vessels, observed practices, equipment maintenance, and port functioning. These issues are and will continue to hinder efficient transport and trade across the lake and the following recommendations are issued in that regard.

Monitoring and Data Collection need to be systematized. It was found that trade and shipping activities are currently not systematically recorded and numerous data and information is not available for analysis. This is important to assess port functioning, improve efficiencies, inform planning and future investments, raise revenue and secure financing.

Navigational Safety can be improved in many ways to reduce the number of accidents and shipwrecks, and increase the operational longevity of vessels and port equipment. Based on preliminary findings, a thorough and dedicated Navigation Needs Assessment for the Lake is recommended, as well as the development of a program to improve the safety and efficiency of navigation in the Lake and its ports. The main issues are as follows:

- Installation of aids to navigation in the vicinity of ports, approaches and specific coastal areas.
- Nautical charts for navigation is the support for safe navigation. The high resolution bathymetries used before and after dredging can be used to support the development of accurate nautical charts.
- Radio communication between ships and shore stations.
- Safety equipment and incident preparedness of ships as well as training of crews and coastal parties involved in search and rescue operations; increase in search and rescue capabilities, well prepared and equipped lake patrol boats; a safety coordinating office for relevant operations.

Port operations and transport networks could see their efficiency improved by strengthening the capacity in almost all areas related to management and operations in lake transportation and ports. Capacity building for vessel crews and port staff.

Sanitation and health concerns cover a range of areas where interventions are needed. Concerning shipping and ports in the lake, the implementation of good practices of garbage and waste management on ships and in ports is a must. A compliant waste reception facility for the port of Kigoma would cost approximately 2.0 million USD. Concerning the basin, a lack of adequate sanitation infrastructure leads to fecal contamination of water resources and the lake. Open defecation is prevalent, and many urban areas lack both a formal sewerage system and an established solid/liquid waste disposal facility (Rutagemwa 2010, West 2001). Fecal contamination in the lake and the lack of sanitation periodically results in diseases, including amoebiasis, bilharzia, cholera, and typhoid.

Environmental regulations to prevent pollution and protect the water quality of the lake will be very important to minimize impacts of transport and other sectors to other activities in the lake, such as fishing, tourism, drinking water supply and the environment. The lack of regulations regarding waste disposal, engine leakages, and overall practices regarding contamination is already a visible reality. Although the Basin is relatively less industrialized than other areas in Africa, untreated industrial effluent flows into the lake from numerous industries in Bujumbura, industrialized fishing in Mpulungu, and cotton and sugar processing plants in the DRC (West 2001). Significant concentrations of pesticides and fertilizers (phosphorous, nitrogen) from agricultural activities and oils from commercial enterprises also contribute to reduced water quality (Rutagemwa 2010), as does mercury and other chemicals used in small-scale gold and diamond mining (West 2001). The reduction of water quality has adversely impacted drinking water provision within the region, and increased costs of water treatment (Rutagemwa 2010).

5. MAIN CONCLUSIONS

Sedimentation in the ports is the main problem leading to reduced water depths. Regular and periodic dredging is recommended in order to ensure sufficient operating depths in the ports. Additional complementary measures to reduce sediment transport into the ports, such as coastal structures, sediment traps and soil conservation measures are also recommended. For regular dredging, ports need to determine the frequency and extent of dredging in the ports and access channels, and secure appropriate equipment and financing mechanisms, port-specific or collective.

This report, its findings, and the data collected, will directly inform ongoing studies of the Lake Tanganyika Transport Program within the broader setting of the Integrated Corridor Development Strategy, and future programs on transport, environment, and natural resource management. In this context, we recommend further analysis on (a) the economic rationale for regular dredging considering current and future cargo and passenger transport in the lake, as well as (b) the financing and institutional arrangements to ensure sufficient revenues and budgeting for a regular and well-functioning dredging program in the ports.

Current projects to enhance the role of lake transportation in the region need to be complemented with appropriate environmental analysis and regulations to ensure a well-balanced exploitation of the Lake. Transforming the lake into a maritime highway with poor regulations will lead to detrimental impacts to other sectors: drinking water, fisheries, biodiversity and the environment.

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Annex: Map of Lake Tanganyika (from Bergonzini et al., 2015)