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Analysis of the Morphology and Lithology of the Kisangani–Yangambi Section of the Congo River in the Democratic Republic of Congo[6]

ABSTRACT

The Congo River, which is between 900 and 300 metres wide between the city of Kisangani and the town of Yangambi, is characterised by important socio-economic and conservation activities but also by a lack of knowledge on morphological and lithological matters. To fill the gaps, the lithology and the morphological dynamics of the riverbed were studied through a description of islands (between 1984 and 2017) and banks thanks to remote sensing and field work, respectively. With regard to the number of islands, the study revealed a loss of 5.13% and a recovery of 28.21% between 1984 and 2017. The direct factors of this dynamism are the erosion and landslides observed both on the banks and on the islands. The geological survey method allowed the collection of 4 samples of sound indurated rocks and 50 samples of loose rocks on the soil profiles of the islands and banks. The macroscopic description and sieving of the samples with 63 mm and 2 mm mesh size allowed the lithology map to be drawn up. The fine soil particles were analysed in the soil laboratory using the Robinson–Köhn pipette method to determine their texture. The USDA textural classification was used. The results of the analysis showed that sand is the predominant rock element in the area. Such a lithology would increase the sensitivity of the banks to mass movements observed here and there along the Kisangani–Yangambi river section.

Keywords: erosion, island, riverbed, lithology, remote sensing, Congo River

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INTRODUCTION

In its quest for "good ecological status" of aquatic environments, the Water Framework Directive of 23 October 2000, adopted by the European Parliament, considers hydromorphological conditions as one of the parameters for assessing the ecological quality of water (Melun, 2012). Nowadays, the world is facing the effects of climate change, to which humans are important contributors. The repercussions are perceptible on rivers and associated resources (Delpla et al., 2009; Bauwens et al., 2013; Le Groupe d'experts intergouvernemental sur l'évolution du climat [GIEC], 2014) and more particularly on the Congo Basin (Commission Internationale du Bassin Congo-Oubangui-Sangha [CICOS], 2015). As a result, Mandango (1982) warned that the Congo River and its tributaries were already playing a considerable role in construction and destruction. The Congo River is an excellent communication route through which important trade takes place between Kisangani and Kinshasa. In addition to the two cities mentioned above, important agglomerations, as well as entire series of activities and infrastructures are installed along the river. Moreover, the river contains a multitude of islands of great biological wealth, thanks to which conservation was initiated first at Yangambi by the Belgian King's decree of 22 December 1933, instituting INEAC (now INERA: National Agricultural Study and Research Institute) with its corollary, the Yangambi Biosphere Reserve (Toirambe et al., 2011), including some of the islands in the Congo River; then on Kongolo Island and Mbie Island by the Faculty of Sciences of the University of Kisangani. However, the above-mentioned socio-economic and conservation activities were undertaken without any prior assessment of the river's morphological dynamics and lithology. Therefore, this study will focus on the description of the morphological and lithological characteristics of the riverbed on the Kisangani–Yangambi section. In addition, the direct causes of the riverbed dynamics will be elucidated on the investigated section. However, the study does not claim to be exhaustive in establishing a model of the dynamics of the Congo River bed[7].

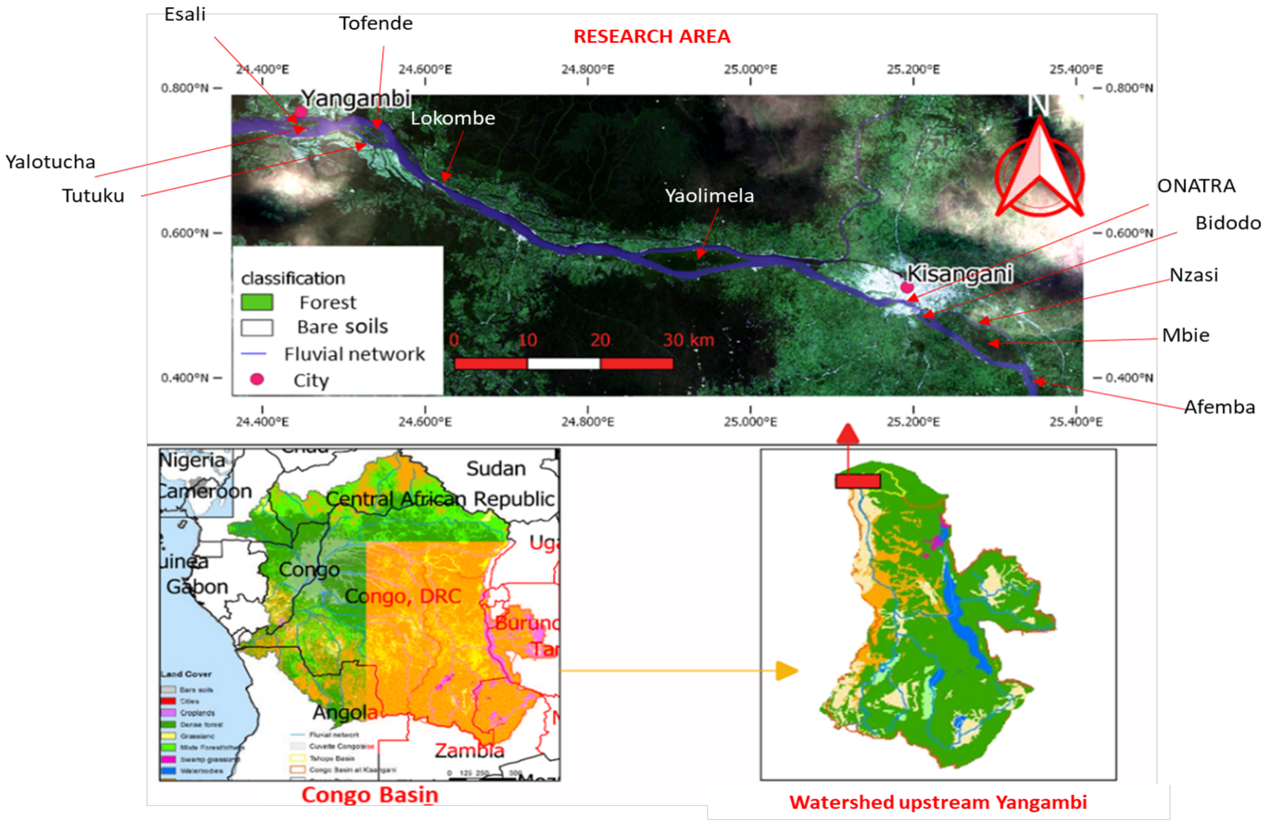
METHODS

Research area

According to Global Land Cover 2000, the watershed upstream Yangambi (Figure 1) is dominated by dense forest (39%), wooded savannah (44%), forest and other mosaic (9%), grassy savannah (2%) and agricultural land (6%). The lithology consists of 70% of metamorphic rocks, 17% of soft sedimentary rocks, 10% of clastic and siliceous sedimentary rocks, 2% of evaporites and 1% of alkaline volcanic rocks (Hartmann & Moosdorf, 2012).

[7] The publication of articles related to the analysis of river morphology and mapping methods is not without precedent in Modern Geográfia (Gashi et al., 2023; Bugya, 2007; Kiss & Bugya, 2014).

Figure 1. Location map of the research area



Source: GPS and Landsat data

The Kisangani–Yangambi section is composed almost entirely of soft sedimentary rocks. Concerning hydrography, the Afemba-ONATRA (National Transport Office) reach is not navigable. It has a width of 900 metres on average and its main feature is the Wagenia Falls. The reach between ONATRA's port and the city of Yangambi is navigable. From ONATRA to Wilia Island (15 km), the Congo River flows over a rocky bottom, which outcrops here and there during the low water period (July–October). The Lindi and Tshopo rivers flow into it at 15 km on the Kisangani–Yangambi road. Between Yaolimela Island (Belgica: 25 km) and Lokombe Island (60 km), the Congo River flows without encountering any islands for 35 km between almost parallel banks with an average width of 1,200 m. From Lokombe, the banks become narrower and only 520 m wide. After the confluence of the Lubilu River with the Congo River downstream of Lokombe, the Yangambi cliffs begin. The average width of the bed increases to 2,600 m and the islands occupy more than 20% of the total surface area (Mandango, 1982).

Numerical description of the islands in the period 1984–2017

The counting of islands was carried out using Landsat images from 1984 and 2017 (Table 1). Then, thanks to the geographical coordinates and by the use of motorized and non-motorized canoes, a verification of the remote sensing results was carried out *in situ*. For verifying the presence or absence of the island, we took the geographical coordinates corresponding to the centre of the island from the map. Then, we integrated them into the GPS. Once in the field, we proceeded to locate each of these islands using the compass of the device through the "GO TO" option. The compass shows us the direction to follow and the distance to the island. Finally, we take the canoe to reach our target.

Table 1. List of images used in the study

Number	*Satellite*	*n° of the tile*	*Date of acquisition (MM/DD/YYYYY)*	*Water level*
1	Landsat 5	176-60	09/20/1984	2.71
2	Landsat 8	176-60	05/10/2017	3.06

The images were taken in September and May with markedly different flows. Uniformity of resolution for both images was adopted for comparison purposes. During processing with QGIS 3.0 software, the images were geometrically corrected and then cut according to the study areas, and the RGB colours (Red, Green and Blue) were assigned to the bands 4, 3 and 2, corresponding to soil, vegetation and water, respectively.

The islands referred to here are portions of exposed and vegetated land in the watercourse with a minimum size of two pixels (0.18 ha). In contrast, sandbanks are not inventoried in this study, as they are not only the base of a developing island, but are also easily eroded due to the low cohesion of loose sand. The inventory was carried out using QGIS 3.0 software by creating a shapefile in which specific encoding and symbology was assigned to (i) islands present in 1984, (ii) those formed after 1984, (iii) those present in 1984 and 2017, and (iv) those present in 1984 but gone before 2017 (Figure 2).

At the end of the inventory, the data from the attribute table were imported into the Excel spreadsheet. Then calculations of the numbers corresponding to each type of island have been carried out, taking into account their presence in the various sections. The same calculations led to the establishment of the proportions and 10-year rates of disappearance and recovery according to the formulas below:

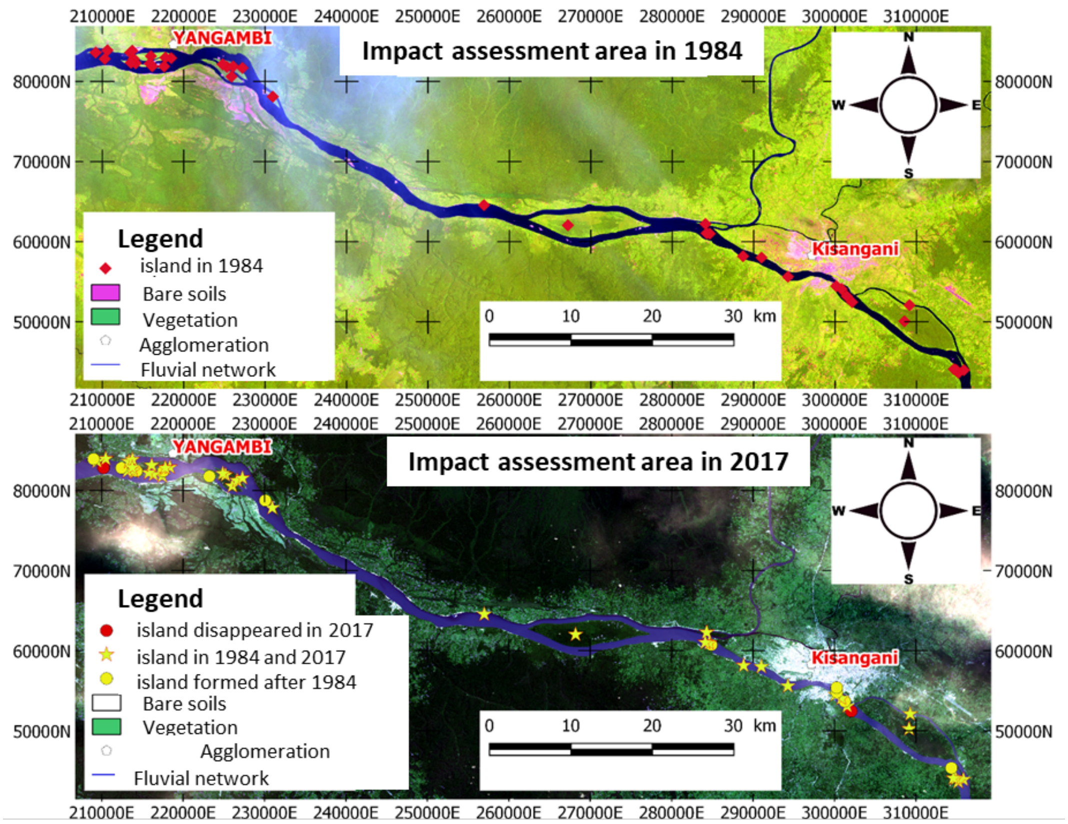
$$\text{DDR}\ (\%) = \left[\frac{DY\ (\%)}{nY}\right] * 10$$

With DDR (%) = Decennial Disappearance Rate in %, DY (%) = Disappearance in % over a number of years X, nY= number of years at the end of which the disappearance was assessed.

$$\text{DRR}\ (\%) = \left[\frac{RY\ (\%)}{nY}\right] * 10$$

With DRR (%) = Decennial Reconstitution Rate in %, RY (%) = Reconstitution in % over a number of years X, nY = number of years after which the disappearance was assessed.

Figure 2. Systematic inventory of islands in the Kisangani–Yangambi river section



Source: Landsat data, by Mawa et al.

Bank dynamics

The description of bank dynamics was carried out by direct observation of mass movements (erosion, rockfall and landslides) both on the mainland and on the islands, oral information and the measurement of the distance between the banks and fixed structures or objects that were once installed on the mainland and are now in the water. A sample of four islands present in 1984 and 2017 was selected for *in situ* morphological descriptions and lithological studies (Appendix 2: Figure 16–17).

Collection and processing of loose and indurated rock samples

The geological survey method allowed the collection of four samples of sound indurated rocks and 50 samples of loose rocks on the soil profiles of the islands and banks. Before any sample is taken, the rock is first described at the outcrop and its geographical coordinates taken and recorded with the GPS and in the field book. The photo of the outcrop is then taken by the digital camera. The geologist's hammer was used to take samples of the indurated rocks. These were subjected to cold hydrochloric acid tests to discriminate between calcareous carbonate rocks and non-carbonate and dolomite rocks. As hot hydrochloric acid was absent, we were unable to verify the presence of dolomitic carbonate rocks. After a description by macroscopic observation with a magnifying glass of 10, a nomenclature was given to the rock according to the predominant minerals it contained. The names of the rocks were validated after the comparison of their characteristics with those of similar samples from geological research in the same region, the thin sections of which were made at the laboratory of the University of Lubumbashi (UNILU) in the DRC. As for the samples of loose rocks, they were taken and processed by the method of Dugain (1958). A rock sample of 2 to 3 kg was taken from each layer (horizon) according to the different compositions of the soil profile. The description of the outcrop and its photo helped us interpret and validate the results of the laboratory analysis. The sample is then packed in a plastic bag, labelled and repacked in two other plastic bags to avoid tearing the packaging and to prevent risks related to the mixing of particles. In addition, the samples were air-dried and then sieved at the University of Kisangani's soil laboratory (UNIKIS).

As organic matter was not important, it was removed from the sample before weighing. To separate coarse and fine soils, 2 mm and 63 mm mesh sieves were chosen in accordance with the USDA (United States Department of Agriculture) standard for soil particle size classification (USDA–NRC, 2002). The rejects from each of these two mesh sizes were weighed to obtain the proportions of gravel and pebbles, respectively. The proportion of the sand-silt-clay complex was obtained from the weighing of the passings at the 2 mm mesh size. This treatment allowed the lithological distribution map of the investigated section to be established. The 2 mm mesh passings were used for the textural analysis. They were first crushed before being analysed using the Robinson-Köhn pipette method (Blaise, 2000; Kombele, 2004) in the pedology laboratory of the Yangambi Faculty Institute of Agricultural Sciences (IFA/Yangambi). The proportions of clay, silt and sand thus obtained enabled us to establish the soil types using the R software, based on the "soil texture" package. The USDA textural classification was also adopted because it is better adapted to tropical soils (Food and Agriculture Organization of the United Nations [FAO], 2003; Kombele, 2004; Alongo et al., 2013). Finally, to characterise the distribution of fine soil types, we calculated the Shannon Diversity and Pielou's Evenness Indices.

RESULTS

Island counts between 1984 and 2017

The Kisangani–Yangambi reach has a large number of islands. There were more islands in 2017 than in 1984. In 1984, there were 39 islands in the section, the majority of which (56.41%) were in the Yangambi area. In 2017, 48 islands were counted. The number of islands has evolved with a decadal disappearance rate (DDR) of 1.51% and a decadal recovery rate (DRR) of 8.3% (Figure 2). Overall, a 5.13% loss of island numbers has been recorded over the last three decades. The losses are equally distributed between the two sections. Despite these losses, 28.21% of new islands were formed, of which 15.38% in the Belgica–Yangambi section and 12.82% in the Kisangani–Belgica section (Table 2).

Table 2. Results of a systematic inventory of islands on the Kisangani–Yangambi section

Island categories	Kisangani Region		Yangambi Region		Total	
	Staff	Proportion (%)	Staff	Proportion (%)	Staff	Proportion (%)
Present in 1984	17	43.59	22	56.41	39	100.00
Present in 1984 and 2017	16	41.03	21	53.85	37	94.87
Present in 1984 but absent in 2017	1	2.56	1	2.56	2	5.13
Absent in 1984 but present in 2017	5	12.82	6	15.38	11	28.21

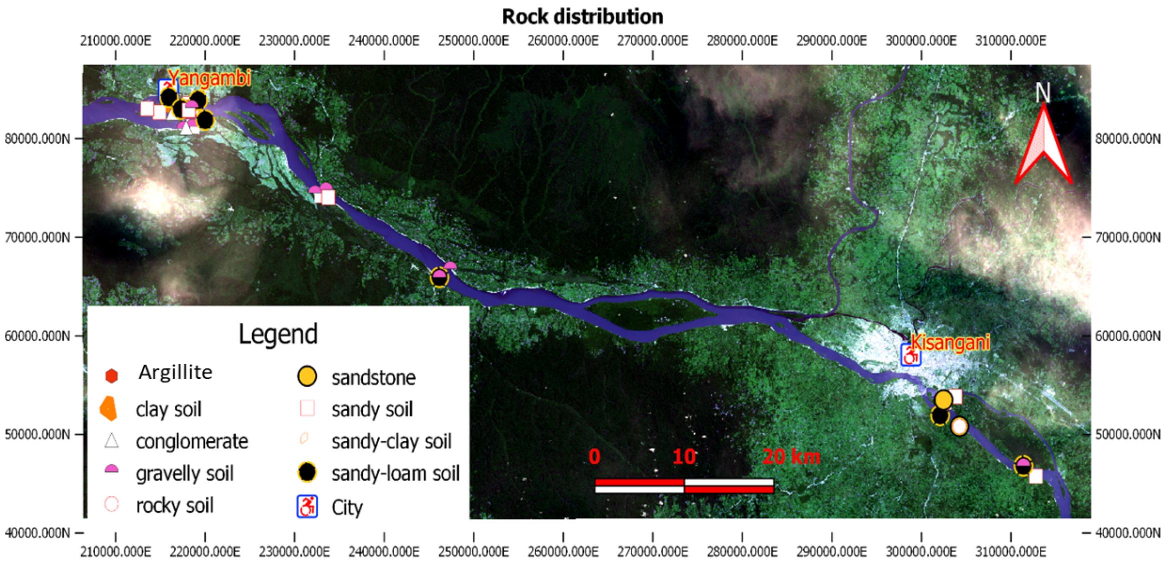
Source: Mawa et al.

Lithological context

Types and distribution of loose and indurated rocks

The entire Kisangani–Yangambi section of the Congo River is dominated by loose rocks, including sandy, gravelly, sandy-loam, sandy-clay and clay soils. They are observed in the upper part of the soil profile. On the other hand, in the lower part of the profile, indurated rocks such as Argillite, sandstone and conglomerate are present (Figure 3). Argillite and sandstone are much more visible in the Kisangani area, both on the islands and on the banks, upstream of Bertha Island. They therefore constitute the rocky bottom on which the river flows. In the Yangambi area downstream of Bertha Island, on the other hand, sandstone is the most widespread, while conglomerate is only visible in places on the left bank. The water flows over the rocky bottom, which is mainly sandstone. This, unlike the sandstone in the Kisangani region, is in a very advanced state of weathering.

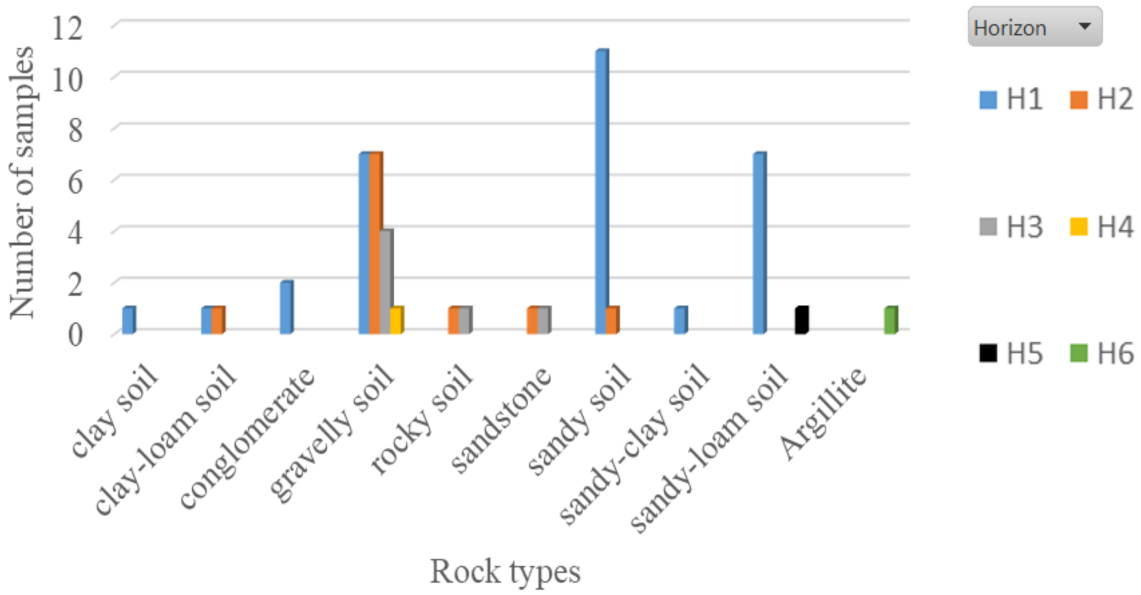
Figure 3. Distribution of loose and indurated rocks on the Kisangani–Yangambi river section



Source: Mawa et al.

Vertically, the upper layer represented by horizon 1 is composed of rocks of several categories. This is the horizon where pieces of clay and silt are predominantly accumulated. Gravelly soil is present in most of the layers from horizon 1 to horizon 4. Sandstone and mudstone are only present from horizon 2 to horizon 6, respectively (Figure 4). However, the order of the horizons is not respected over the whole section.

Figure 4. Distribution of loose and indurated rocks by horizon (depth)



Source: Mawa et al.

Soil characteristics and classification on the basis of particle sizes below 2 mm

The Kisangani–Yangambi section of the Congo River consists of 6 sediment and bedload types: clay (Cl), clay loam (ClLo), loamy sand (LoSa), sand (Sa), sandy clay (SaCl), sandy clay loam (SaClLo) and sandy loam (SaLo).

In the Kisangani region, sand is the most abundant bedload and sediment type (47.21%). It remains dominant on the mainland, while on the islands it is dominated by the sand and silt-sand complex (Figure 5B). Soil types are more diversified on the mainland (H = 1.243) than on the islands (H = 0.965). As for their distribution, the soil and sediment types on the shores are much more evenly distributed (J = 0.897) than those on the islands (J = 0.879; Figure 5C).

In the Yangambi area, sand is also the most dominant (31.11%). It maintains its dominance on the mainland, while on the islands the dominant soil type is sandy-clayey silt (Figure 6B). On the other hand, soils on the mainland are more diversified (H=1.62) and have a disproportionate distribution (J=0.83). In contrast, on the islands, the soils are less diversified (H=1.27) and tend to have a uniform distribution (J = 0.92; Figure 6C).

Figure 5. USDA textural triangle of the sub-2 mm diameter fraction of soils in the Kisangani region (A) and related soil types (B) and diversity and equitability indices (C)

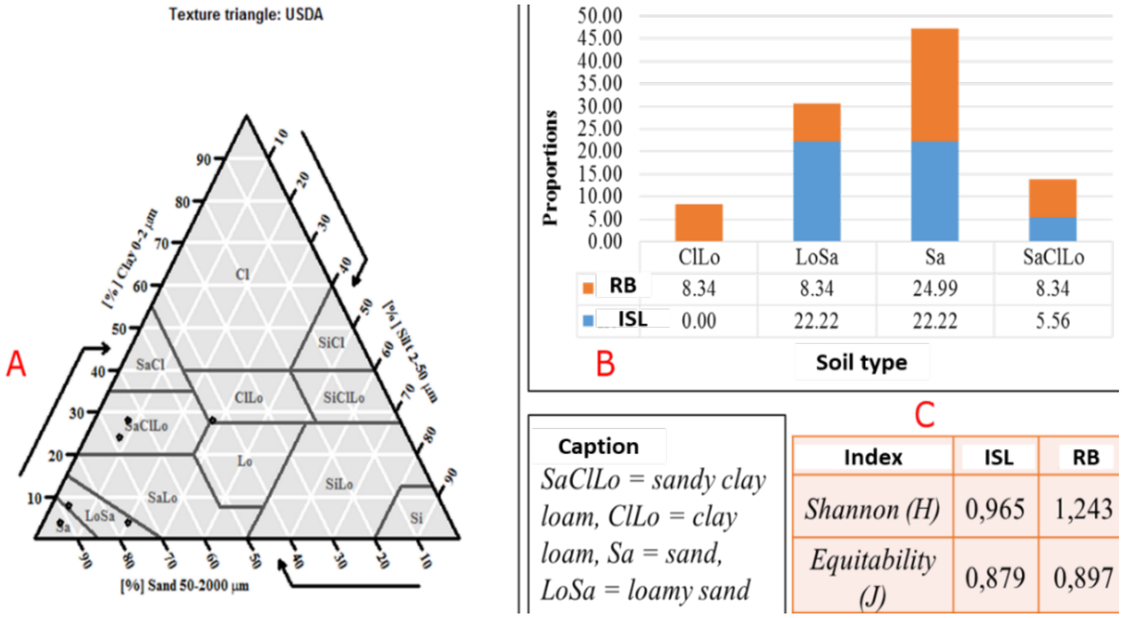
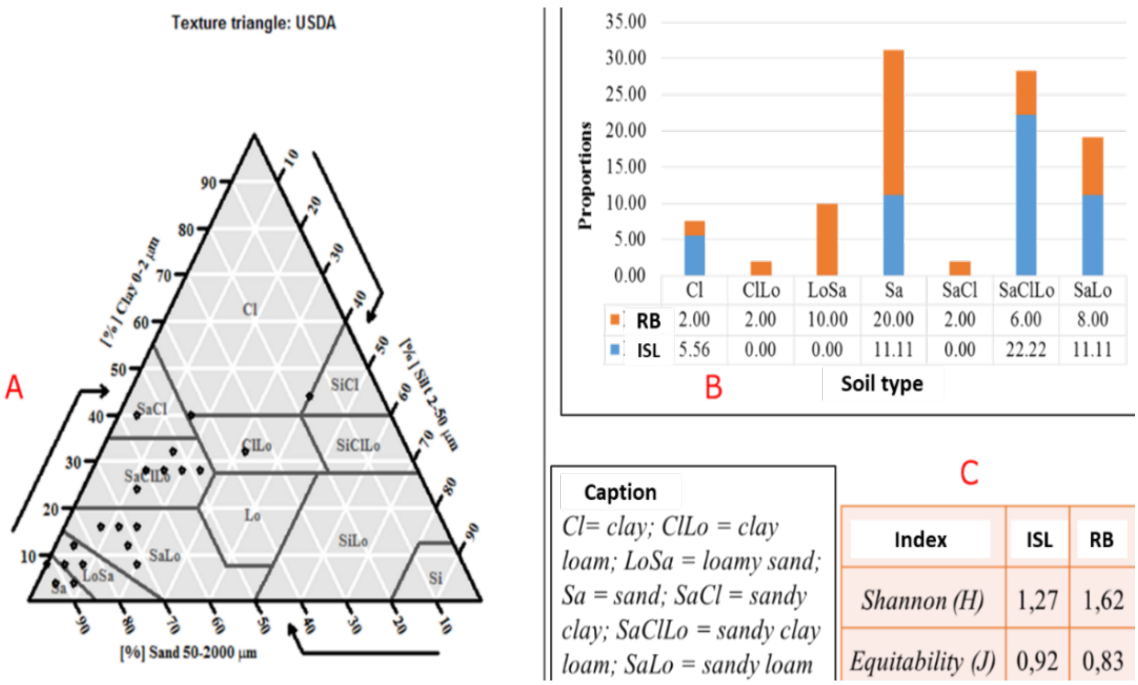


Figure 6. USDA textural triangle of the sub-2 mm diameter fraction of soils and sediments in the Yangambi area (A) and sediment and soil types (B), as well as the related diversity and equitability indices (C)

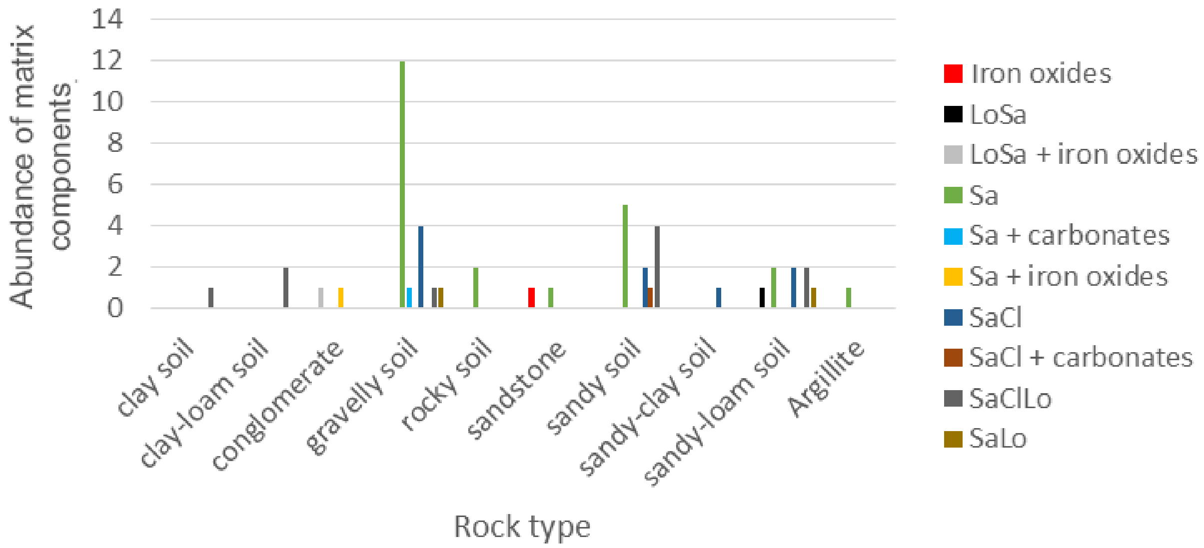


As can be seen in Figures 5 and 6, all four soil types found in the Kisangani region are also present in the Yangambi region. However, the Yangambi area differs from the Kisangani area in the presence of three soil types: clay, sandy clay and sandy loam. Most of the results of this analysis show sand as the main soil and sediment component in the Kisangani–Yangambi river section.

General observations on the lithology of the Kisangani–Yangambi river section

The macroscopic description of the rocks and the analysis of the fine elements show the types of elements that make up the matrix of the coarse rock. Thus, iron oxides and sands constitute the matrix of sandstone and conglomerate. In addition to its presence in the Argillite, calcite is also present in some gravelly rocks. Similarly, we also noted sand inclusions in argillite (Figure 7).

Figure 7. Distribution of fine particles in loose and indurated rocks



Source: Mawa et al.

Description of the factors of the geomorphological dynamics of the riverbed

Erosion and landslides threaten the stability of the bed of the Kisangani–Yangambi section. On the Kisangani–Belgica section, these movements have led to the opening of the minor bed of the right branch of the river at Mbie Island and the reduction of the island's width by 4.26 m (Figure 8A) in less than 10 years. Both upstream and downstream and all around the tree, we have seen losses of island area. Loose, bare soil is more affected by land movement (Figure 8B) than vegetated soil. According to a 50-year-old resident of the same island, the right river branch was ±30 m away from their village. However, trees such as the strangler fig and sandstone lithology provided an effective screen regarding the evolution of mass movements on the banks of Mbie Island (Figure 8A). On the right bank, in addition to erosion, landslides are recorded here and there along the minor bed and have caused windthrow (Figure 8C). Similarly, on the left bank, erosion is recurrent (Figure 8D).

On the Belgica–Yangambi section, the same mass movements were observed, particularly on Esali Island (Figure 9 B1). They pose a strong threat to the island forest through the presence of impending (Figure 9 B2) and actual (Figure 9 B3) windthrow on the island's shores. On Yalotucha Island, on the other hand, sediment accretion is the phenomenon observed on the whole island (Figure 9 C1), despite the erosion that has affected a very small portion of the upstream part (Figure 9 C2). On the left bank, recurrent erosion and landslides lead to a large number of windfalls, affecting trees of all sizes throughout the section (Figure 9D). These mass movements have led to a rapid widening of the minor riverbed and a reduction in the size of villages along the river. This is the case in the villages Yaokombo, Yalikolo and Yase 2 (Appendix 2, Figure 17). According to an interviewed resident of Yaokombo village, Mr Wako Batale Noé, the river is significantly reducing the size of their village and damaging the infrastructure. Moreover, in less than 10 years, they have moved the road three times and their hospital is being impacted by the retreat of the riverbank due to landslides. After all the calculations, the latest mass movements (erosion + landslide) have resulted in a loss of ± 3 m of the mainland in less than 5 years.

Figure 8. Mass movements, impacts and the role of trees in bank protection on the Kisangani–Belgica section. Result of erosion and landslides reported by residents on Mbie Island (A), erosion on Mbie Island (B), landslides on the right bank (C), landslides and erosion on the left bank (D)

Figure 9. Mass movements, impacts and the roles of trees in bank protection in the Belgica–Yangambi section.

Predisposition to landslide by the opening of schistosity planes (A1), evidence of the widening of the middle bed from an engineering structure (A2), bank erosion channel and landslide (A3) along the right bank, landslide leading to imminent landslide (B1), imminent windthrow (B2) and actual windthrow (B3) at Esali Island, sediment accretion (C1) and incipient erosion (C2) at Yalotucha Island, informed widening of the middle riverbed as a result of erosion and rockfall on the left bank at Yaokombo village and the actual windthrow and imminent width they cause (D).

CONCLUSIONS

In 1932, Fourmarier explained the essential characteristics of the physical geography by the evolution of the region over the course of geological periods. In France, Grivel and Gautier (2012) demonstrated, on the basis of diachronic studies carried out on the Loire from 1850 on, that the main channel had undergone a very high degree of lateral mobility, and thus put forward the hypothesis that this mobility would seem to be linked to the strongest depressions on the Loire. Under the same hypothesis, they assert that the large islands were formed in the areas of greatest lateral (over 300 metres) and vertical (over 8 cm) mobility. From the same perspective, the Kisangani–Yangambi river section experienced a lateral expansion of the minor bed as demonstrated by the mass movements observed here and there along the minor bed. Within the minor bed, 5.13% of old islands have been extinguished and 28.21% of new ones have been formed. However, the sinking of the bed was not verified due to time and material constraints, and we could not calculate the areas of the newly formed islands to be able to evaluate the compensation. As for the authors Dauphin and Lehoux (2004), they explain the reduction in the surface areas of the islands by erosion. Berg (1961) explains the importance of the annual loss of soil in the Congo River basin in general and in particular in Kisangani by the minute quantities of salts dissolved in the basin. However, this last aspect has not been taken into account in our study. For his part, Cahen (1954) had already noted in the same study area a low quantity of suspended solids and an absence of earthy elements in the large tributaries and thus justified them by the presence of sedimentary deposits in the depressed areas of the basin.

Further downstream, Dinga et al (2011) noted in 2010 the presence of silting in the Stanley Pool that had not been seen for nearly 65 years. The authors explain the phenomenon by the impact of climate change on the hydrological regime of the Congo River and the erosion in its catchment area. Generally, the authors are unanimous that the lithological type of the entire Kisangani–Yangambi section is made up of rocks whose essential element is sand. This result corroborates what De Heinzelin (1952) and Berce (1964) found, respectively, in the eastern sector of the Congo Basin and the area between the Congo River and the Aruwimi River. The authors state that the more or less wide alluvial plains that extend over the islands of the Congo River are characterised by a very fine sandy lithology to which a small amount of silt is added. The presence of this type of lithology is justified by the geological and geomorphological contexts of the region; such is the progressive filling in during the geological periods of the central basin by sediments coming from the erosion of the rocks of the whole catchment area in the studied section. The lithology of the investigated fluvial section is made up of loose and indurated rocks. The movements of the masses are not important on the latter since they are compact and occupy the lower horizons. Concerning the loose rocks, in the Kisangani area, as well as in the Yangambi area, sand is the most dominant. It is abundant both on the mainland and on the islands in the Kisangani region, whereas sandy-clayey silt dominates the islands in the Yangambi region. The similarity in predominant constituents in the two regions is justified by their belonging to the same hydrogeomorphological context. Sand, as demonstrated by Dias et al (2015), is less resistant to the stresses of hydroclimatic agents. Indeed, dry and clean sand has no cohesion, but clayey sand has a weak cohesion that can be destroyed by agitation in water. Since the soil is loose and located in the upper horizons, the sand constituting the matrix is thus easily leached and the rock structure is offered. This leads to large mass movements such as landslides and rockfalls when the slope of the bank is steep. The debris is then transported by water and deposited downstream in the river bed. This justifies the rate of the reconstruction of islands found in this study. This result is similar to that of Tricart (1977) in the Brazilian Amazon, where the author explained the dynamics of riverbeds in part by the interference between azonal factors including lithology.

The Congo River, in its part between the cities of Kisangani and Yangambi, has a very dynamic bed. The width of its bed is between 900 and 3000 metres. It has an impressive number of islands, of which 5.13% were lost between 1984 and 2017 and 28.21% of new ones were formed during the same period. In addition to the erosion and accretion of material on the islands, there is also significant mass movement on the riverbanks, which has led to the widening of the riverbed. This phenomenon is a consequence of the lithological composition. The region contains indurated rocks such as clay, sandstone and conglomerate on the one hand, and loose rocks such as stony soils, gravelly soils, sandy soils, sandy-loam soils, sandy-clay soils and clay soils on the other. The analysis of soil particles with a diameter of less than 2 mm showed that sand is the predominant element in the constitution of the different soil types. Having a low cohesion, sand is the main factor that has amplified the movements of the masses when stressed by hydroclimatic factors. It would also appear that the coarse structure of the soil facilitates landslides. However, mass movements are slowed down on indurated rocks and under trees with long tap roots. Thus, it is important that further research establish a model of bank dynamics by relating the rate of mass movement (erosion and slumping) to factors such as bank slope height and slope, plant root density, vegetation cover, soil structure and texture, water height and current velocity. Compensation for losses should also be calculated from sediment accretion rates. This exercise will thus enable the establishment of a general model of the dynamics of the Congo River bed.

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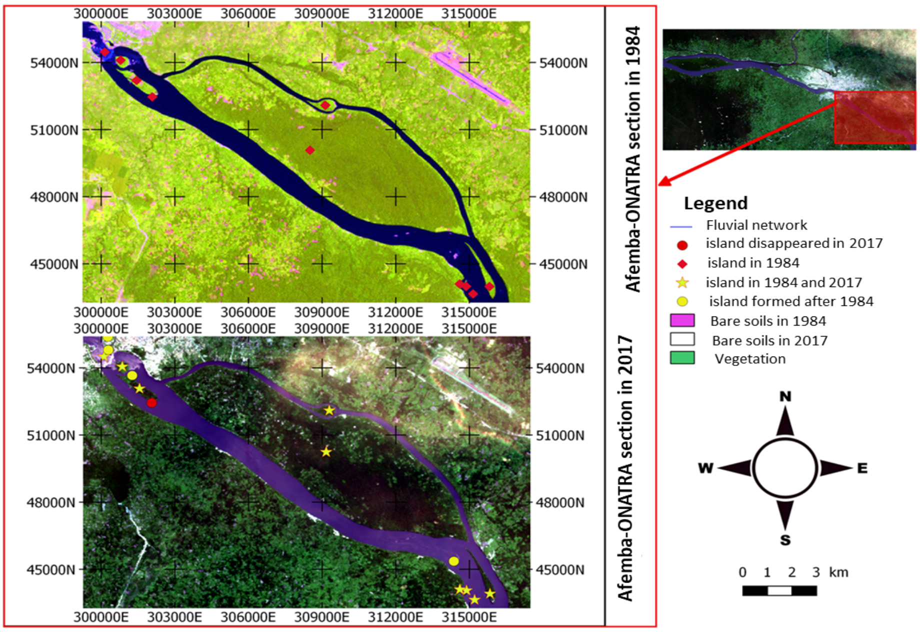
APPENDICES

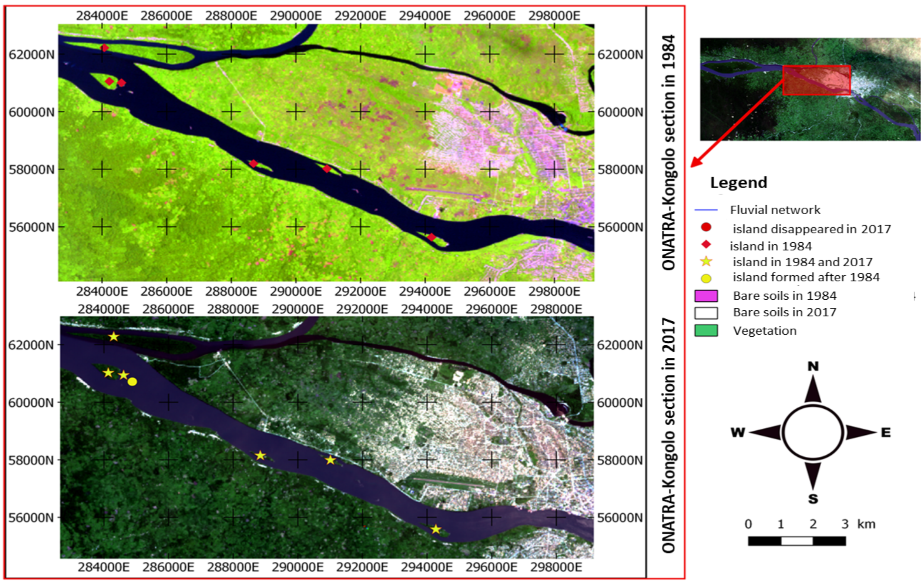
Appendix I: Counting of islands' details on the islands in the Kisangani–Yangambi section in 1984 and 2017

Figure 10. Map of the islands of the Kisangani region, case of the Afemba–ONATRA section



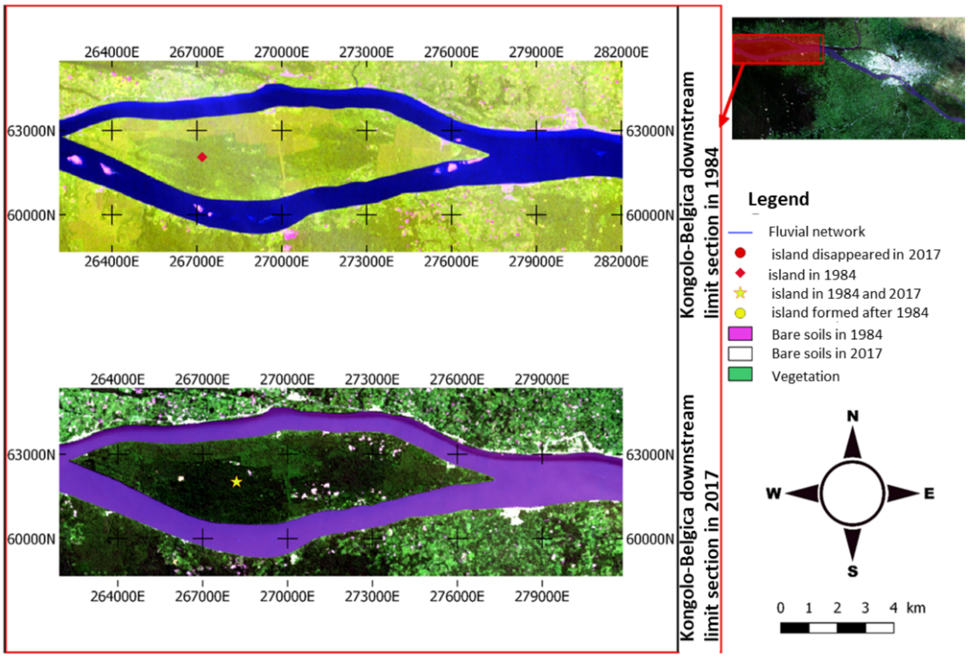
Landsat data, by Mawa et al.

Figure 11. Map of the islands of the Kisangani region, case of the ONATRA–Kongolo section



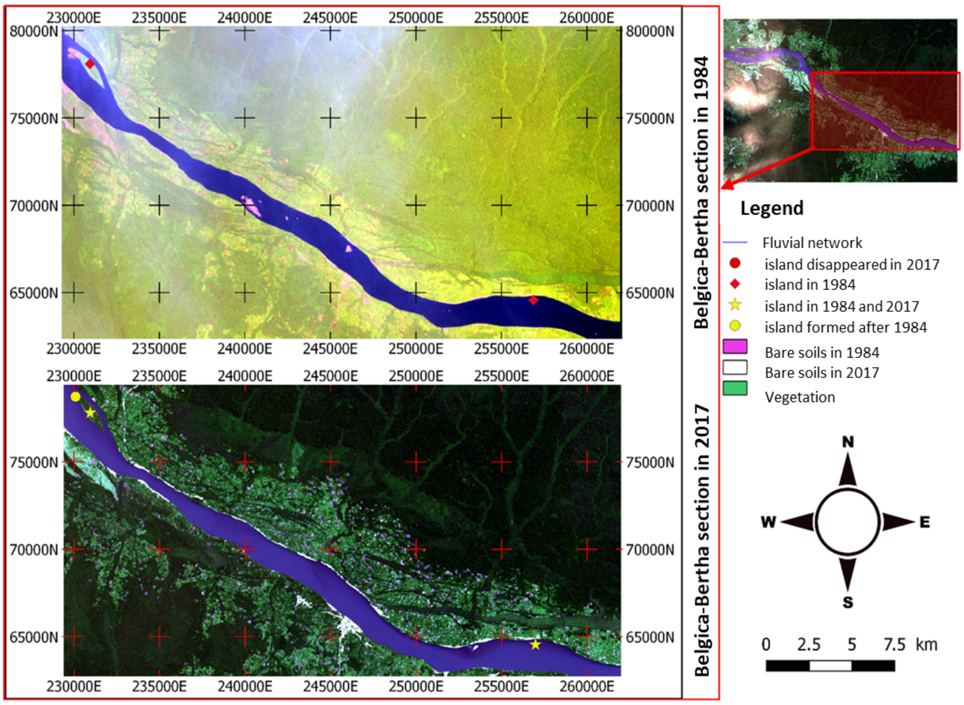
Landsat data, by Mawa et al.

Figure 12. Map of the islands of the Kisangani region, case of the Kongolo–Belgica section



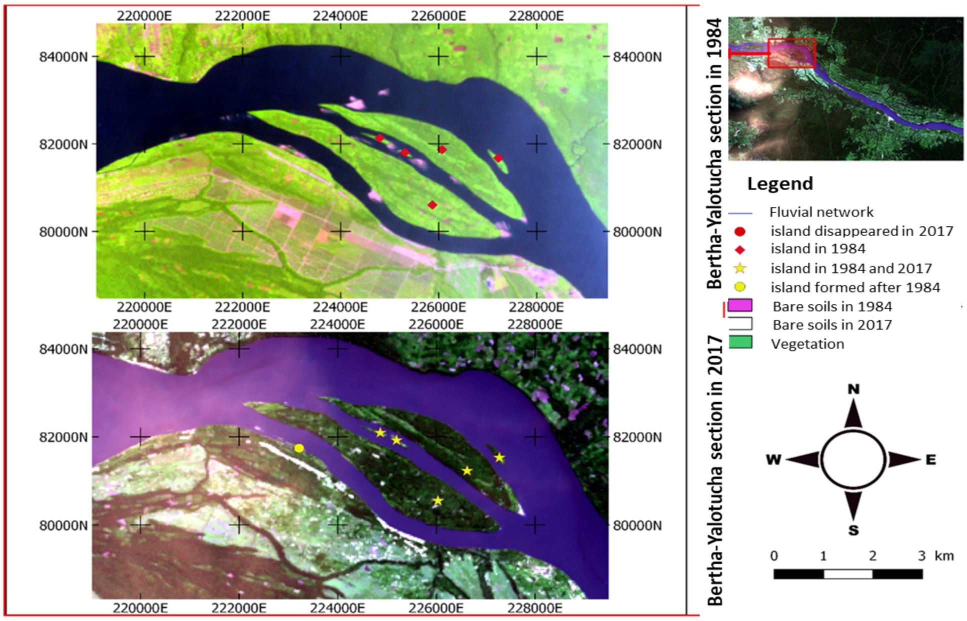
Landsat data, by Mawa et al.

Figure 13. Map of the islands of the Yangambi region, case of the Belgica–Bertha section



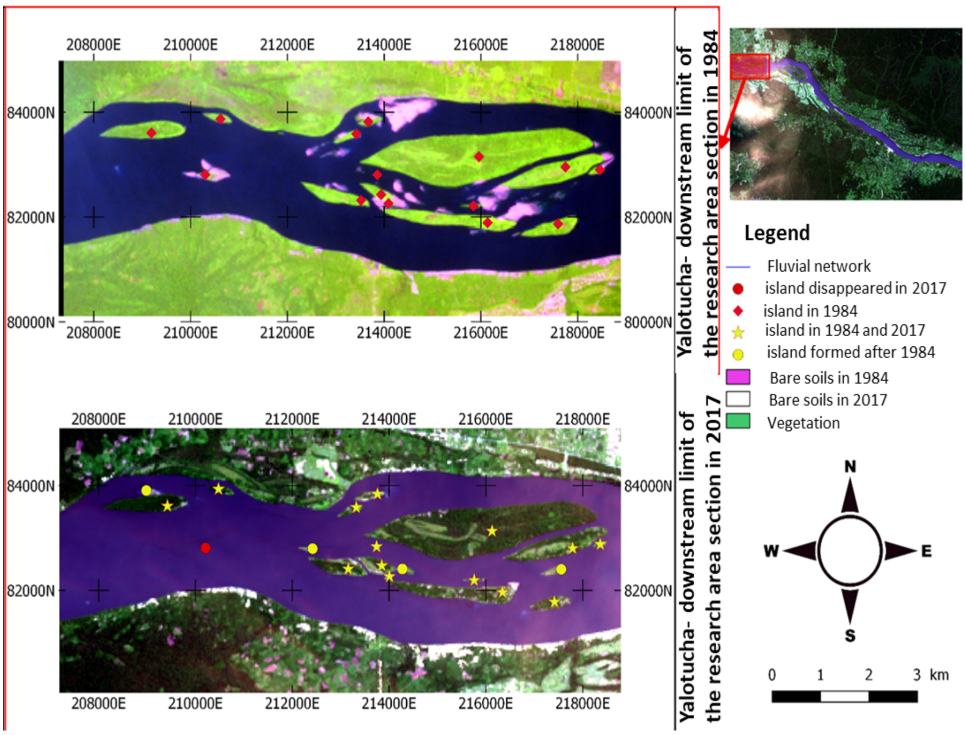
Landsat data, by Mawa et al.

Figure 14. Map of the islands of the Yangambi region, case of the Bertha–Yalotucha section



Landsat data, by Mawa et al.

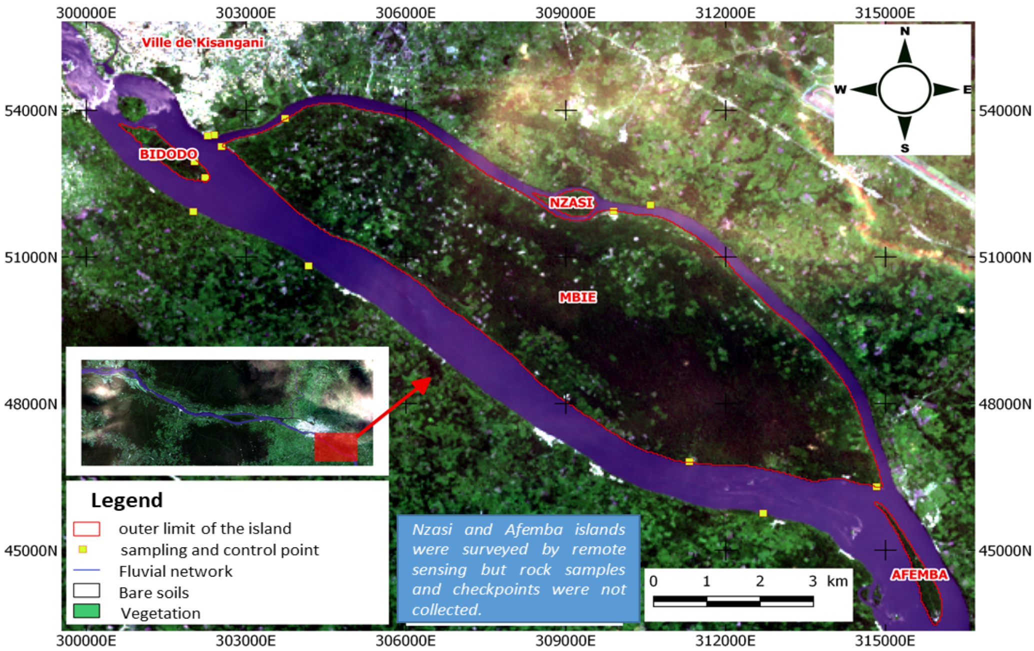
Figure 15. Map of the islands of the Yangambi region,
case of the Yalotucha–limit section swallows of the research area



Landsat data, by Mawa et al.

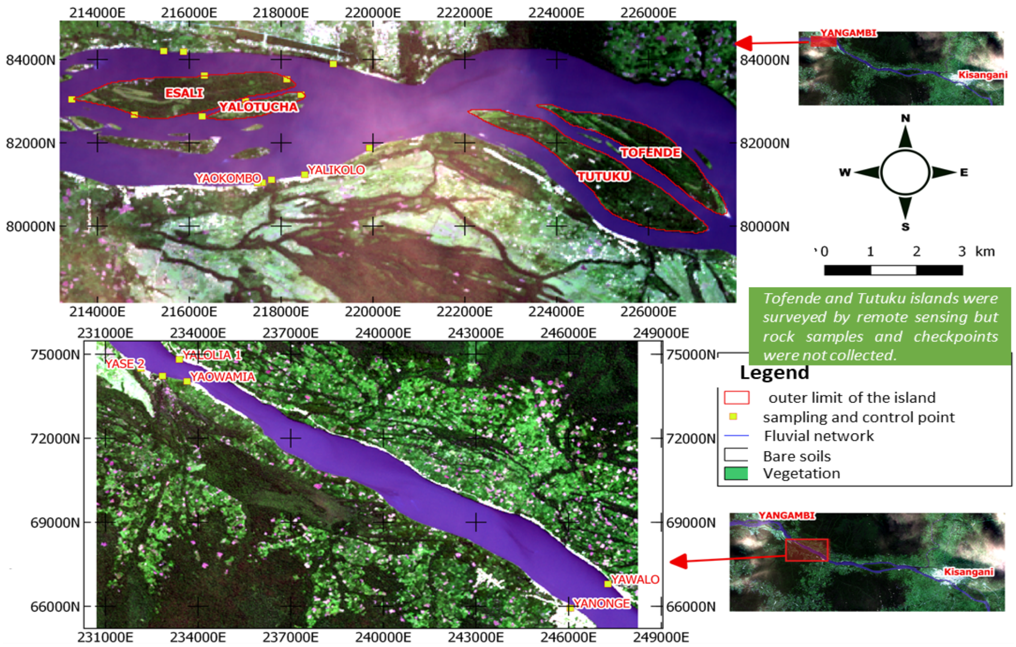
Appendix II: soil sampling and verification of in situ remote sensing results

Figure 16. Map of rock samples and checkpoints data collection in the Kisangani region



Landsat and GPS data, by Mawa et al.

Figure 17. Map of rock samples and checkpoints data collection in the Yangambi region



Landsat and GPS data, by Mawa et al.

Appendix III: Description of the main lithological types

Healthy Argillite constitutes the base of Bidodo Island (Figure 20A1). It is compact, characterised by a greenish-grey colour and consists of very fine minerals (clay). The rock has a large scale-like shape on the surface. This shape is related to the drying cracks due to the drying of the clay. Calcite inclusions (the rock is effervescent in places at 10% cold HCl) and fine quartz grains are also noticeable in its structure. At Mbie Island, however, the sound rock is not effervescent (Figure 20A2). In some places it is observed to be in an advanced state of weathering (Figure 20A3). It is characterised by the reddish colour of the iron oxides and the pearl grey colour of the clay. The upper horizon of this rock consists of gravelly soil. Small angular pebbles (d≤20 mm) are contained in a loose mass consisting of sandy-clay particles (Figure 20A3). At Mbie Island, as on the right bank of the river, sandstone outcrops (Figure 20B). The rock is indurated and compact. It is characterised by the reddish colour of the iron oxides and consists of sand with dimensions similar to those of sugar grains. Inclusions of quartz grains are also noticeable in its structure. On the banks of the left bank straddling Mbie Island, a stony soil consisting of blunt pebbles with diameters ranging from a few centimetres to ten centimetres can be observed in the outcrop (Figure 20C1) and in the sample (Figure 20C2). On the upper horizon, both on the islands and on the banks, we find sandy-clay soil (Figure 20D). Mixed with water, it sticks to the fingers and the shrill sounds of the sand are barely perceptible to the ear. The rock is reddish-grey in colour and loose. It has very small minerals that are difficult to see with a 10x magnification lens.

Figure 18. The main lithological types of the Kisangani region

Downstream of Bertha Island, the sandstone is in a very advanced state of weathering (Figure 21A) on the riverbed and on the right bank. Sand is abundant, and iron oxides give the rock yellow and reddish hues. Small quartz crystals are also visible in the rock structure. On the left bank opposite Yangambi, the soil profile has a yellowish and reddish lateritic conglomerate at the base (Figure 21B). The quartz grains are embedded in an iron matrix. The rock is indurated and compact. It has a coarse structure. The nodules vary within the dimensions of millimetre and centimetre in size. Above this horizon, we find the gravelly soil. It is a loose rock, yellowish grey in colour, made up of quartz grains of millimetre size. The matrix surrounding the grains is a silty type of sand. The sandy-clay soil (Figure 21C) of Yalotucha Island is made up of fine elements and is grey in colour. The reddish tones of iron oxides can also be observed. The presence of small cavities is probably related to the dissolution of salt minerals. On the right bank, at Yangambi, two horizons are visible on the soil profile (Figure 21D). The sandy soil at the base of the profile is enriched with iron oxides, hence the reddish colouring. On the upper horizon grey silt-clay soil can be observed. Its particles are finer than those of the previous sandy horizon.

Figure 19. The main lithological types of the Yangambi region