Application of Geospatial Techniques for Monitoring Gikondo Wetland Management: from Industrial Park to Eco-Tourism Park

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Abstract— *For several years, Gikondo Wetland has been serving as home for industries, warehouses, garages, and was critically degraded by various anthropogenic activities since its establishment as industrial park in 1960s. The objective of this study is to analyse quantitatively and qualitatively the dynamics of Gikondo Wetland degradation and its rehabilitation progress from industrial to eco-tourism Park. Geo spatial techniques (GIS and Remote Sensing) have been used to analyse changes induced by management techniques from 1987 to 2019. Results show that wetland area has reduced from 32.03% (1987) up to 25.70% (2010) indicating its degradation due to the increase of built up areas and bareland over the wetland area. From 2010 to 2019, the area of wetland has increased. This positive change of land cover is indicating a good progress of Gikondo wetland restoration process. Continuing reinforcement of national legal framework is required and the implantation of development programs should be done with minimum tradeoffs in order to achieve the transformation of this former industrial park into an eco-tourism park. Rehabilitation process should consider wetland functions, services, and replacement options for achieving sustainable use and management of wetlands in Rwanda.*

Keywords— Geospatial techniques, Gikondo Wetland, Industrial Park, Historical Dynamics, Eco-tourism Park.

I. INTRODUCTION

In 1950, only 30 % of the world's population was urban. In 2018, the world's population was residing in urban areas reached 55 % and the figure is estimated to be 68 per cent by 2050 (UN, 2019). Cities and towns are continuingly becoming the primary human living space as countries develop. However, different studies highlight that accelerated urbanization is blamed to have negative impacts on urban environment especially on wetland ecosystems. This is due to fact that many world wetlands were taken as wastelands, difficult to use for agriculture or urbanization purposes.

The above perspective has found place in Rwanda wetland management. Rural urban migration, high population growth, and provision of improved urban infrastructures such as roads and industries have contributed to increased urbanization by 26.70%. Moreover, lack of coordination between environment and urban planning sector has contributed to human occupation of wetland ecosystems especially in Kigali. Residential expansion, industrial and commercial activities have contributed to the loss or degradation of wetlands of Kigali city. Uncontrolled engineering activities have contributed much on destruction of wetland flora and fauna. In the same vein, the lack of effective wetland management strategies has resulted in the development of infrastructures such as roads and buildings within wetland area.

The case of Gikondo wetland has drawn the attention on the underperformance of industry and urban planning. This wetland, stretching from Gikondo to Nyabugogo was selected as industrial area since the independence. Therefore, it was greatly affected, and its ability to control siltation, and clean wastewater and buffer flooding was jeopardized[2]. The development of some infrastructure such as factories, warehouses and paved roads has reduced the surface area available for infiltration, and the increased runoff causes erosion on bare soils and siltation of water ways in the lower parts of the wetlands.

It was until 2005 that the government of Rwanda started to establish the clear linkages between development and sustainable wetland. In this regard, the Rwanda government promulgated the Organic Law on Environmental Management and established the agency charged with supervision, follow-up and ensuring of environment mainstreaming in all national and local policies. The policy making has continued to focus on the importance of the Gikondo Wetland. Following the publication Sustainable Development Goals, specifically the SDG 11 on "Make cities inclusive, safe, resilient and sustainable and its inclusion in the National Strategy for Transformation NST1 in its objective 6 on "Sustainably exploit natural resources and protect the environment", The Gikondo Wetland received the policy attention due to its functions and services. This shows that the motive to restore this wetland is enshrined in the above international, national and local

policies. This calls for the need to provide decision making on historical evolution of the functions and services of the Gikondo Wetland to guide future decision making in the restoration and sustainable use of this wetland.

However, there have been few studies on the integration of the Gikondo Wetland restoration in the sustainable urban management of Kigali. For instance, Bizimana & Schilling, (2010) have studied the flood risks and stressed the importance of integrating flooding risks in Kigali Master Plan. Kabanda, (2008)has analysed the level of environmental compliance to organic law in Gikondo wetland. His study demonstrated not only the low level of compliance, high level of violation and lack of capacity to monitor the violation in Gikondo Wetland. Etale,(2011)has studied the risks of cadmium and lead uptake from agriculture products farmed in Gikondo Wetland and demonstrated that high Cadmium and Lead concentration exceeding the EU standard. In the same vein, Sekomo et al., (2011)have analysed pollution level in Nyabugogo Wetland, and showed that pollutant from Gikondo Industrial Park were discharged without treatment in Nyabugogo Wetland. In sum, these studied have demonstrated environmental and health risks posed by inefficient management of the wetland. However, none of them has shown the spatial dynamics of these risks through a spatio-historical perspective. Therefore, this study aims at using geo-spatial technology to unravel historical dynamics of the degradation of Gikondo wetland to guide future decision in the sustainable use of Gikondo Wetland.

II. MATERIAL AND METHODS

2.1 Description of the study area

Gikondo Wetland is located in three districts, Gasabo, Nyarugenge and Kicukiro . Gikondo study area has over 385.39 hectares. The wetland is surrounded by small mountains inhabited on all the sides (fig.1). This wetland has been used as industrial park. However, there has been a plan to relocate the industries and convert the wetland to Gikondo Lake Park for nature based tourism attraction site in Kigali city. The park will feature indigenous plantation and allows passive recreation use [7]. The figure below illustrates some examples of wetland parks highlighted in Kigali City Master Plan.

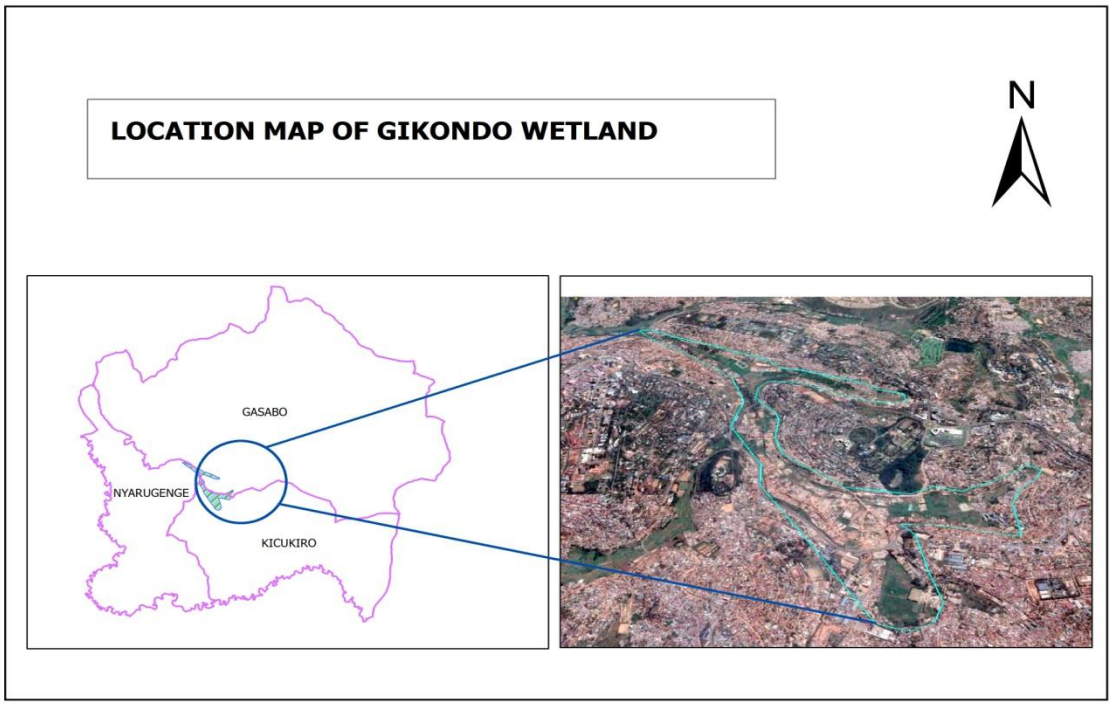

FIGURE1: Location of the study area

2.2 Methods

2.2.1 Data collection

This study has sought to use spatial data spanning long time series (ranging from 1987 to 2019). Therefore, Landsat imagery was found suitable as it provides historical data for almost 40 years and free availability. It also has a much better spectral resolution, which is important for land cover classification. Landsat images were downloaded in separate files from the United State Geological Survey (USGS) through the website which is https://earthexplorer.usgs.gov. To advance to high

level of details, Building Stock and Building Typology of Kigali, Rwanda [8] was collected to produce the building footprint and building archetypes using the Pleiades satellite images produced in 2009 and 2015.

2.2.2 Data analysis

Data analysis was conducted in three steps. Firstly, the image processing was carried out using Texture analysis through Gray level co-occurrence matrix (GLCM) features. This was performed to be integrated in the classification. GLCM-Variance which was identified as best performing texture measures while combined with spectral bands and NDVI for generally improving land cover classification accuracy [9] and particularly isolating formal and slum areas in urban environment. Secondly, the ENVI 5.3.1. software was used for image classification. Before proceeding with the classification, it is important to know the data to use and the number of classes.After getting training samples, pixel-based Support Vector Machine (SVM) classification was done using ENVI 5.3.1. This method is able to avoid over fitting problem and requires no assumption of data type. Although no-parametric, the method is capable of developping efficient decision boundaries and therefore can minimize misclassification [10].And finally, the post classification was done using the new training samples selected by using the Region of Interests (ROIs). In this study, a combination of local knoweledge (socio-economic features) with remotely sensed data was done in order to gain better insights into urban land uses more accurately. It is in this regard that after post-classification refinement, the following overall accuracies and Kappa coefficients were obtained.

TABLE 1
CLASSIFICATION ACCURACIES AND KAPPA COEFFICIENTS

Period	1987	2000	2010	2019
Overall accuracy	81.04%	86.30%	83.70%	85.70%
Kappa Coefficient	0.78%	0.81%	0.79%	0.82%

III. RESULTS AND DISCUSSION

Results show that land cover has been changing for 32 years. The built up area has increase at the expense of the wetland. In 1987, the landscape of Gikondo was dominated by wetland. However, the increased human occupation led to the encroachment at large extent until 2010. This human settlement encroachment on wetlands was driven by the importance of this wetland as source of land for industrial construction and private dwellers. That is why the wetland area has considerably decreased untill 2010. These anthropogenic activities were motivated by the lack of coordination among government insitutions on ecological importance of this urban wetland.

However, a shift was observed in the period between 2010 and 2019.There was an increase in wetland area but it is still bellow its extent in 1987. The wetland area increased by 25.70% from 2010 to 2019. Despite this increase, the wetland area has not recovered to the 1987 extent (32.03%). Bare land has been increasing from 1987 (5.28%) to 2019 (8.82%) with high pick in 2010 (9.66%) (Fig.2 and 3). This indicates that within wetland boundary there is a degraded space requiring more restoring activities.

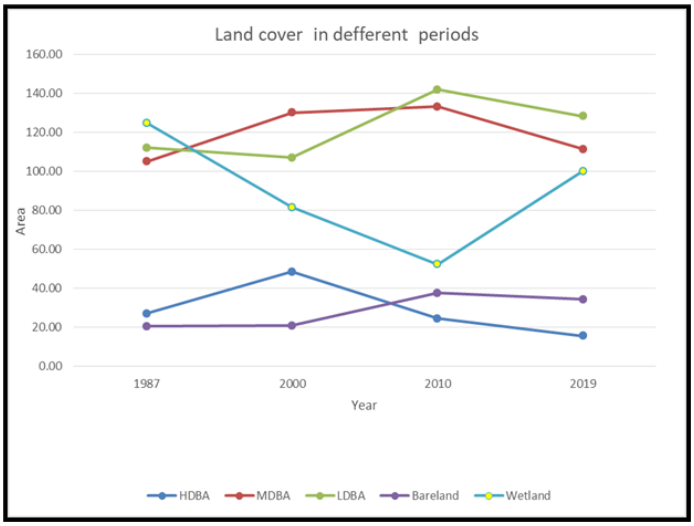

FIGURE 2: Land cover evolution from 1987 to 2019

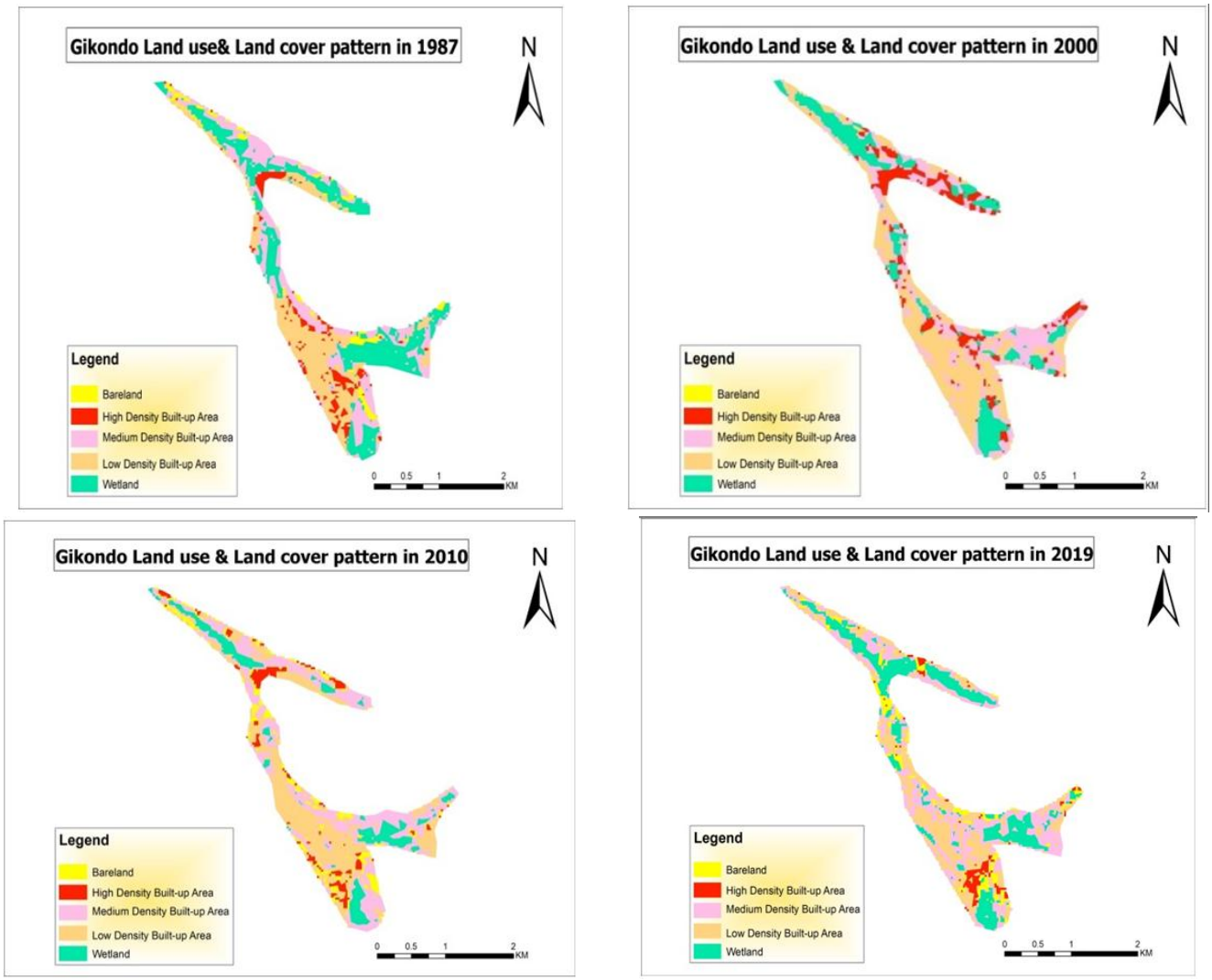

FIGURE 3: Spatial changes and land cover in different periods

In addition, other laws were promulgated and supported and were implemented to conserve the wetland. They include: 1) Law N°10 of 02/05/2012 governing the urban planning and building in Rwanda [12]. This law requires the city of Kigali and districts to develop master plans in which different land uses conforming to environmental regulations are established. 2) The Law N° 43 of16/06/2013 governing Land in Rwanda [13]stipulates that wetlands constitute public land and construction in wetland are prohibited. This law served the ground for the relocation of the industrial park in Gikondo. In addition, it is in the framework of this law that the Prime Minister promulgated the Order N°006/03 of 30/01/2017 drawing up a list of swamps, lands, their characteristics and boundaries and determining modalities of their use, development and management.4) The Law N° 70 of 02/09/2013 governing biodiversity in Rwanda (GoR, 2013) establishes not only endangered ecosystems but also those that needs to be protected due to the national importance[14]. Finally, the Law N° 32/2015 of 11/06/2015 relating to expropriation in the public interest (GoR, 2015) establishes activities of public interests for which expropriation will be undertaken. Through this laws industries owners were compensated with industries facilities in Kigali Special Economic Zone. Referring to this law, the ministry of Trade and Industries issued the instruction n°20/MINICOM/2013 of 20/05/2013 modifying instructions n°15/2012 of 23/04/2012 related to the relocation of factories and other facilities located in the Gikondo industrial park [15]

The implication of the mainstreaming of the Gikondo Wetland in the Kigali City Master Plan has also been revealed by the change in building stock and building typology. The latter shows decrease in buildings between 2009 and 2010. For instance, the number of buildings decreased from 4208 in 2009 to 3455 buildings in 2015. This leads to a decrease of 17.89% in the number of buildings. The building typology "Basic" was predominant with 3358 buildings representing 79.8 % of the total buildings. Most of these buildings are located in the area of informal settlement such Kimicanga, the part surrounding UNILAK. In this year 2015, wetland protection improved as the built-up area decreased from 64.26 ha to 57.01ha. This is

largely due to the relocation of the informal settlement of Kimicanga in 2010. The number of buildings of typology which is "Basic" decreased from 3358 to 2623. This implies a decrease of 21.8%

The restoration of wetland services and replacement options in order to minimize the tradeoffs in wetland functions, services, and replacement options (Table 1). This facilitates its sustainable management and the minimization tradeoffs that usually occur during the implementation of different government policies. The detailed aims to contribute to development of Kigali City as the significant destination for adventure and nature related to tourism. This is why Gikondo Industrial Parks is being converted into Gikondo Lake Park for nature based tourism attraction site in Kigali City. In addition, the rehabilitation of this wetland is considering other functions such as: removal and control of pollutants, flood reduction, groundwater recharge, wildlife habitat, and other services as previous studies have shown higher health risks resulting from heavy metal concentration in soil and water [6].

TABLE 1
GIKONDO WETLAND FUNCTIONS, SERVICES, AND REPLACEMENT OPTIONS

Function	Services	Alternatives
Pollutant removal	Maintain the quality of water; cycle nutrients; retain sediment; filter runoff	To establish water filtration plants where incoming water and sediments are treated before entering in wetland; To develop storm water facilities with water quality criteria around Gikondo wetland
Flood attenuation	Capacity to reduce downstream flood volume; slow flow to reduce peak discharges; protect downstream property; public safety	To adopt storm water treatment practices, dikes and levees construction, and advanced floodplain construction design around and in the wetland
Groundwater recharge and discharge	Maintain base flow conditions in streams	To create artificial lakes within wetland boundaries
Wildlife habitat	Home for aquatic and terrestrial species; support biodiversity; connective wildlife corridors	Wetland restoration, and stocking of new plant and animal species to improve the biodiversity in wetland
Other	Recreation, education, and aesthetics,	Wetland restoration, creation of more urban parks and thematic recreational areas around the Gikondo rehabilitated wetland, and to maintain wetland buffers undisturbed.

Source: Adapted from Wright et al, (2006)

IV. CONCLUSION AND RECOMMENDATIONS

Geospatial technologies based on Geographic Information System and Remote Sensing have the potential to contribute to the understanding of historical and spatial changes in wetland ecosystems services. The use of geo-spatial techniques has shown how the land use change resulted in the degradation of wetland as results of lack of policy integration and coordination in urban planning. This resulted in the increase in built up area at the expense of the wetland area from 1987 to 2009. The same techniques also were able to show that it is possible to monitor the shift in land use policy. They demonstrated that the implementation of a comprehensive legal and institutional framework resulted in the increase in wetland area at the expense of other land use. This means that this shift which is interpreted as the integration of wetland in urban planning policies and related policy coordination has benefit to the resilience of wetland ecosystems in the urban context. Geospatial techniques have demonstrated that changes that are contributing to the recovery of wetland services have been taking place since 2010.

Despite the strength of geospatial techniques, this study has only focus on their application in tracking historical and spatial changes using the land cover/ land use change perspective. The latter has not allowed to track change in water (flooding and drying), and biological and chemical concentration of pollutants. It is imperative that the interpretation in land use/ land cover change be combined with change in moisture and pollution concentration to fully grasp how the restoration in Gikondo Wetland is contributing to the recovery of ecosystems services. There is a need of interdisciplinary study to analyse these changes. This study will not only analyse past change but also future changes resulting from the restoration and recreation use of the Gikondo Wetland.

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REFERENCES

[1] UN, *World population prospects 2019*, no. 141. New York, 2019.

[2] Republic of Rwanda, "Economic analysis of natural resource use in rwanda with a case of land and water resource use in rugezi wetlands," Kigali, 2011.

[3] J. P. Bizimana and M. Schilling, "Geospatial Techniques in Urban Hazard and Disaster Analysis," in *Geospatial Techniques in Urban Hazard and Disaster Analysis*, no. November, 2010, pp. 99–124.

[4] P. Kabanda, "Quality of Compliance and Enforcement of the Environmental Organic Law for Wetland Uses in Kigali City-Rwanda," IHE Delft, 2008.

[5] A. Etale, "Risks of Urban Agriculture: Lead and Cadmium Intake by Kigali Residents from Locally Grown Produce," University of Witswatersrand, 2011.

[6] C. B. Sekomo, E. Nkuranga, D. P. L. Rousseau, and P. N. L. Lens, "Fate of heavy metals in an urban natural wetland: The Nyabugogo swamp (Rwanda)," *Water. Air. Soil Pollut.*, vol. 214, no. 1–4, pp. 321–333, 2011, doi: 10.1007/s11270-010-0426-9.

[7] Kigali City, *Detailed District Physical Plans for Kicukiro and Gasabo*, vol. 1, no. Kigali: Kigali City, 2013.

[8] F. Bachofer *et al.*, "Building stock and building typology of Kigali, Rwanda," *Data*, vol. 4, no. 3, pp. 1–9, 2019, doi: 10.3390/data4030105.

[9] D. Lu *et al.*, "The roles of textural images in improving land- cover classification in the Brazilian Amazon," *Int. J. Remote Sens.*, vol. 35, no. 24, pp. 8188–8207, 2014, doi: 10.1080/01431161.2014.980920.

[10] X. Niu and Y. Ban, "Multi-temporal RADARSAT-2 polarimetric SAR data for urban land-cover classification using an object-based support vector machine and a rule-based approach," *Int. J. Remote Sens.*, vol. 34, no. 1, pp. 1–26, 2013, doi: 10.1080/01431161.2012.700133.

[11] Republic of Rwanda, *Official Gazette of the Republic of Rwanda No . 04 / 2005 of 08 / 04 / 2005 Organic Law Determining the Modalities of Protection , Conservation and Promotion of the Environment in Rwanda*. Rwanda: Office of the Prime Minister, Official Gazette no 9 of 1/05/2005, 2005.

[12] Republic of Rwanda, *Law Governing Urban Planning and Building in Rwanda*, no. May. Rwanda: Office of Prime Minister, Official Gazette n° Special of 30/05/2012, 2012.

[13] Republic of Rwanda, *Law N° 43/2013 OF 16/06/2013 Governing land in Rwanda*. Rwanda: Office of the Prime Minister, Official Gazette No Special of 16/06/2013, 2013.

[14] Republic of Rwanda, *Law N° 70/2013 of 02/09/2013 Governing the biodiversity in Rwanda*. Rwanda: Office of Prime Minister, Official Gazette n°38l of 38/09/2013, 2013.

[15] MINICOM, *Instructions of the minister of trade and industry n°20/MINICOM/2013 of 20/05/2013 modifying instructions n° 15/2012 of 23/04/2012 related to the relocation of factories and other facilities located in the Gikondo Industrial Park*, no. Rwanda: Office of Prime Minister, Official Gazette n° 23 of 10/06/2013, 2013.

[16] T. S. Tiffany Wright, Jen Tomlinson, "Urbanization on wetland quality," Elliot City, 2016.