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Spatio-Temporal Distribution of Water Hyacinth (*Eichhornia crassipes)* in the River Wouri, Littoral Region in Cameroon

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Abstract
Water covers about 70% of the earth's surface. Coastal areas offer unique ecological services and serve as a source of livelihood through fishing, sand mining, and recreational activities. The utility of coastal waters is altered by the addition of foreign substances or weeds, such as water hyacinth. In River Wouri, water hyacinth can be traced right back to 1982. Its distribution over the past 40 years has been evaluated in this study alongside the seasonal changes in 2023. Through the use of geographic information systems and remote sensing technology using ArcGIS and ENVI, the extent of the spread of water hyacinth in River Wouri has been assessed. Transect sampling, that is, plot sampling along the River Wouri was also carried out to evaluate the changes in the weed population in the rainy and dry seasons. The findings of this study revealed that water hyacinth is found in River Wouri all year round. It was also observed that the distribution in the dry season is relatively higher than in the rainy season. Over the past 4 decades, the population of the weed has been relatively stable, with 2002 recording the lowest quantity of the weed, 2012 and 2022 recording the highest quantity.

Keywords
Water hyacinth, *Eichhornia crassipes*, Seasonal changes, Pollution, Weed, Management

INTRODUCTION

Water hyacinth is an ornamental freshwater plant often introduced into lakes, rivers, and ponds (Arefin et al., 2021). The spread to other parts of the world despite originating in Bazil around the 1880s is attributed to its exceptional beauty with bright green leaves and purple flowers (Basaula et al., 2021). As a plant which floats on the water surface, it serves similar functions to terrestrial plants; recycling carbon by absorbing carbon dioxide from the atmosphere during photosynthesis and releasing oxygen beneficial to non-plant organisms primarily animals. Studies have shown that water hyacinth can be used to clean water polluted with heavy metals due to its efficient uptake of nitrogen, phosphorus, and potassium (Harun et al., 2021). Full benefits of this aquatic plant have not yet been fully characterized and explored. In recent studies, it has been seen that water hyacinth can be used for a variety of applications such as feed for animals with little or no augmentation of the feed, enhancing the fertility of agricultural land, and bioenergy production (Ayana, 2021; Ayanda et al., 2020; Harun et al., 2021; Mujere, 2015; Sierra-Carmona et al., 2022; Stefanakis & Becker, 2015).

However, when accidentally or deliberately introduced in slow-flowing rivers and in non-target water bodies with no regulation, it becomes a nuisance. It often outcompetes indigenous aquatic species by reproducing both asexually and sexually bearing seeds that can withstand a dormancy of 20 years (Djihouessi et al., 2023). Water hyacinth is a weed that slows down, interferes, and inhibits the activities of both the aquatic ecosystem and human settlement. Communities reliant on fish catch, sand extraction, and navigation on water to carry out their activities face the unintended consequences of water hyacinth spread (Bamgboye, 1994; Hill & Coetzee, 2008). It disrupts proper ecosystem functions and structure (Enyew et al., 2020; Getnet et al., 2020; Gezie et al., 2018; Thi Nguyen et al., 2015). For instance, dense mats of water hyacinth make fishing difficult for predator birds reliant on fish for their survival and if the situation persists, it can lead to migration of this bird species (Villamagna & Murphy, 2010). Moreover, these mats prevent sunlight from penetrating into water which is needed by phytoplankton to produce their own food (Bayu et al., 2024). It therefore affects food chains and food webs disrupting the ecosystems dynamics of water bodies reducing species evenness and richness (Harun et al., 2021).

Undoubtedly, water hyacinth ranks among the most invasive aquatic plant species worldwide. Its exceptional ability to rapidly spread and thrive in harsh conditions poses a significant threat to entire water ecosystems. Furthermore, its aggressive nature results in the displacement of other species, causing a destructive impact on biodiversity (Yigermal et al., 2020). Over the years, water hyacinth has posed a significant challenge in the past, continues to be a difficult problem to tackle using mechanical, chemical, and biological control methods (Adelodun, 2022; Armenio & Mossa, 2020; Karouach et al., 2022; Nega et al., 2021). Water hyacinth holds the potential for future opportunities (Yan et al., 2017). The trend in water hyacinth literature over the years shows a shift from eradicating the weed due to its ecological impact and economic burden to sustainable management, regulating the spread and lastly, valorizing the weed (Bayu et al., 2024; Djihouessi et al., 2023; Harun et al., 2021; Karouach et al., 2022).

Correctly identifying the water hyacinth is crucial to avoid using a different plant and getting inaccurate results (Opande et al., 2017). According to Opande et al. (2004), the carpet size changes occur twice a year on average. Several studies in literature demonstrate that the measurement of the quantity of water hyacinth coverage in each area involves a comparison between the wet and dry seasons distribution (Thamaga & Dube, 2019).

Previous studies confirm the presence of water hyacinth in various water bodies in Cameroon (Cho, 2012; Kenfack et al., 2019; Nwamo et al., 2022). However, the extent of the water hyacinth spread in River Wouri have not yet been explored. There is limited literature related to the spatial and temporal distribution of water hyacinths in River Wouri (Cho, 2012). The objective of this study was to evaluate the temporal and spatial distribution of water hyacinth in the River Wouri. Two methods were used to evaluate these changes in water hyacinth coverage, that is, seasonal changes through transect sampling (plots sampling) and spatio-temporal distribution through geographic information system and remote sensing technology to analyze the satellite images (1982-2022).

MATERIALS AND METHODS

Study Area

This study was carried out at River Wouri, Douala, Littoral region of Cameroon (Figure 1). Cameroon lies between West and Central Africa, covering an area of 475,440 km^2 including 2,730 km^2 of water. With coordinates: 4°03′N 9°42′E, Douala is the Economic capital and largest city of Cameroon. It is Cameroon's most populated city, with 3.9 million inhabitants in 2021 (United Nations Population Prospects, 2022). Douala has a tropical monsoon climate (Köppen climate classification Am), with relatively consistent temperatures all year. The city is typically warm and humid, with an annual temperature of 27.0 °C and an average humidity of 83%. The dry season last for 4 months from mid-November to mid-March while the wet season last for 8 months from mid-March to mid-November.

River Wouri is the largest river in Cameroon, approximately 160 km long. According to Norbert *et al*., (2019), it originates from River Nkam and flows into the Wouri estuary at the Atlantic Ocean, where it meets the Gulf of Guinea. River Wouri is an important source of water for the city of Douala and its surrounding areas. It is a source of livelihood; fishing, sand extraction, recreation, transportation, and industrial activities (Besack et al., 2021; Norbert et al., 2019). In addition, the river is an important symbol of the country's heritage and identity, and it is featured on the Cameroonian coat of arms. The port of Douala, which is the largest port in Central Africa, is located at the estuary of River Wouri.

Data collection

Distribution of water hyacinth in River Wouri

A reconnaissance survey was used to estimate the spread of water hyacinth in River Wouri in April and September 2023. Figure 2 shows the location of plots and sites distribution over River Wouri. A team of four (A GPS operator and his assistant, the boat operator and his assistant) navigated 19.5km over the River Wouri from the main bridge on the National N°3 road to Bossamba village (Figure 3). Once in the canoe at the level of the bridge, a GPS point was taken and the tracklog function was activated on the GPS devise. At the interval of 500 m, a plot of 20 m x 20 m at the right side of the River Wouri was demarcated to assess the water hyacinth occupancy. At the same time, information about the plot neighborhood was also taken including: GPS coordinates, vegetation type (forest, mangrove, marecage, savanna, farmland, plantation), human settlements, industrial activities). While navigating on the river, all sites with more than 50 m² of water hyacinth in the both sides of River Wouri were recorded and the same information at the plots level were collected. A GPS (Garmin 64x) was used to collect GPS coordinate location for the sample "plots" and "sites" during the navigation in River Wouri from Akwa Nord through Yassem right up to the Bossamba village.

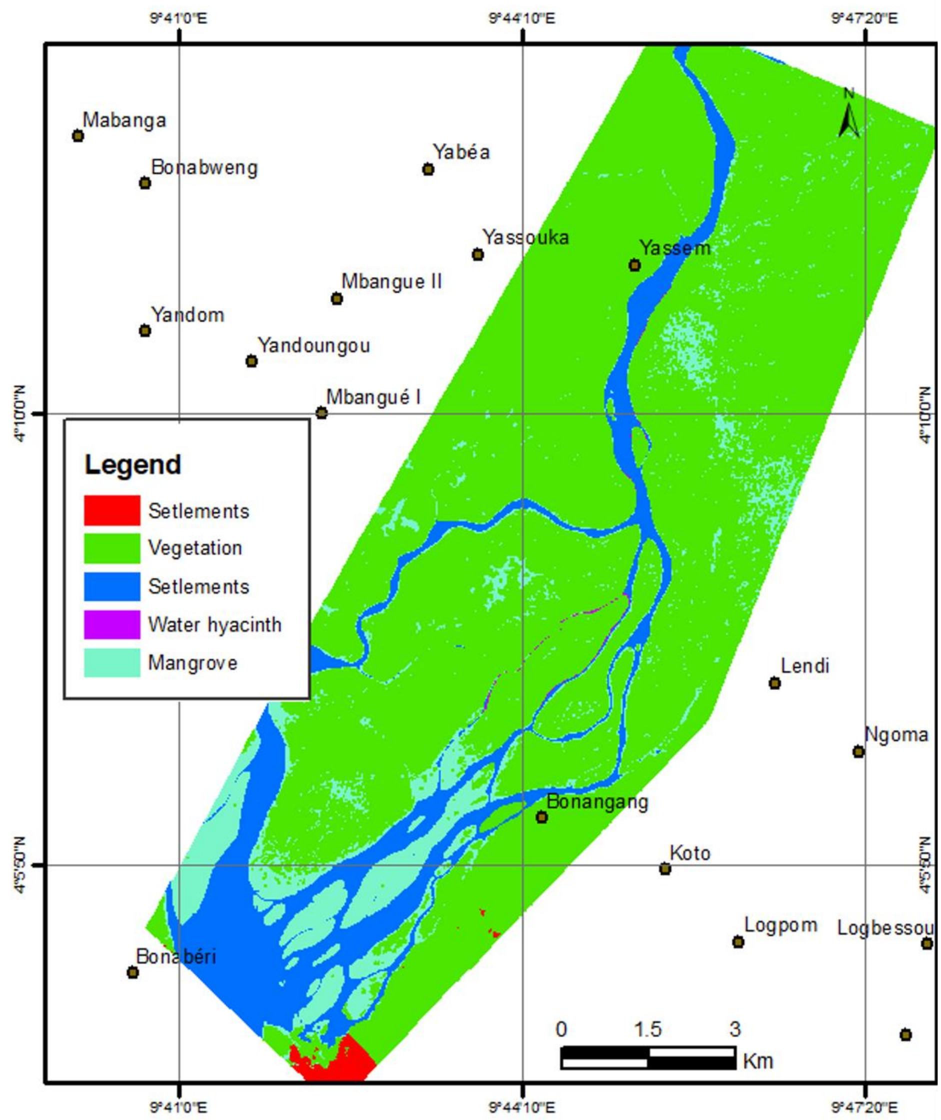

Fig. 1 Location of the study area showing the land cover in River Wouri, Douala.

In addition to comparing the difference in the occupancy of water hyacinth in predetermined sampling locations (plots), the density of the water hyacinth was also evaluated using the total sites with more than 50 m^2 measurement along the track for both seasons, in April (for the dry season) and in September (for the rainy season). Conversely, rather than a plot of 10 × 10 m plot at least 10 km apart (Wu & Ding, 2020), 20 x 20 m plots of 500 m apart and 50 m^2 for sites, were used to estimate the spread of water hyacinth in River Wouri to have greater appreciation of the extent of weed coverage.

Biomass measurement of water hyacinth in River Wouri

Quadrant measurement is used in to estimate the biomass of water hyacinth in each area, Measuring the biomass is done by randomly placing a 1 m^2 frame and collecting the water hyacinth plants that fall into the frame (Opande et al., 2017; Reddy, 1984). The average plant biomass per square meter expresses area coverage by the total mass of the water hyacinth (Janssens et al., 2022; Rommens et al., 2003). For the present study, a terrain tape was used to measure 1 m^2 and 2 m^2 portions in different sections of River Wouri and the water hyacinth was harvested and weighed using a hand scale. Based on the seasonal coverage of water hyacinth on the sample path of approximately 19.5 km, the spread over whole River Wouri (which is 160 km) can be estimated.

Spatial and temporal distribution of water hyacinth (1982-2022)

The spatial and temporal distribution of water hyacinth was determined by downloading and analysing satellite images over a 10-year interval. Five multispectral satellite images specifically 1982, 1992, 2002, 2012 and 2022 were downloaded. This selection allows for a comprehensive analysis of temporal changes in land cover and land use over an extended period. The details of the collected satellite data, including sensor type, acquisition date, cloud cover percentage, projection system, and spatial resolution, are presented in Table 1. The data were selected to ensure minimal cloud cover and optimal image quality, allowing for accurate analysis of land cover changes. The selection of sensors from Landsat and Spot ensures consistency in data quality while providing the necessary resolution for detailed analysis.

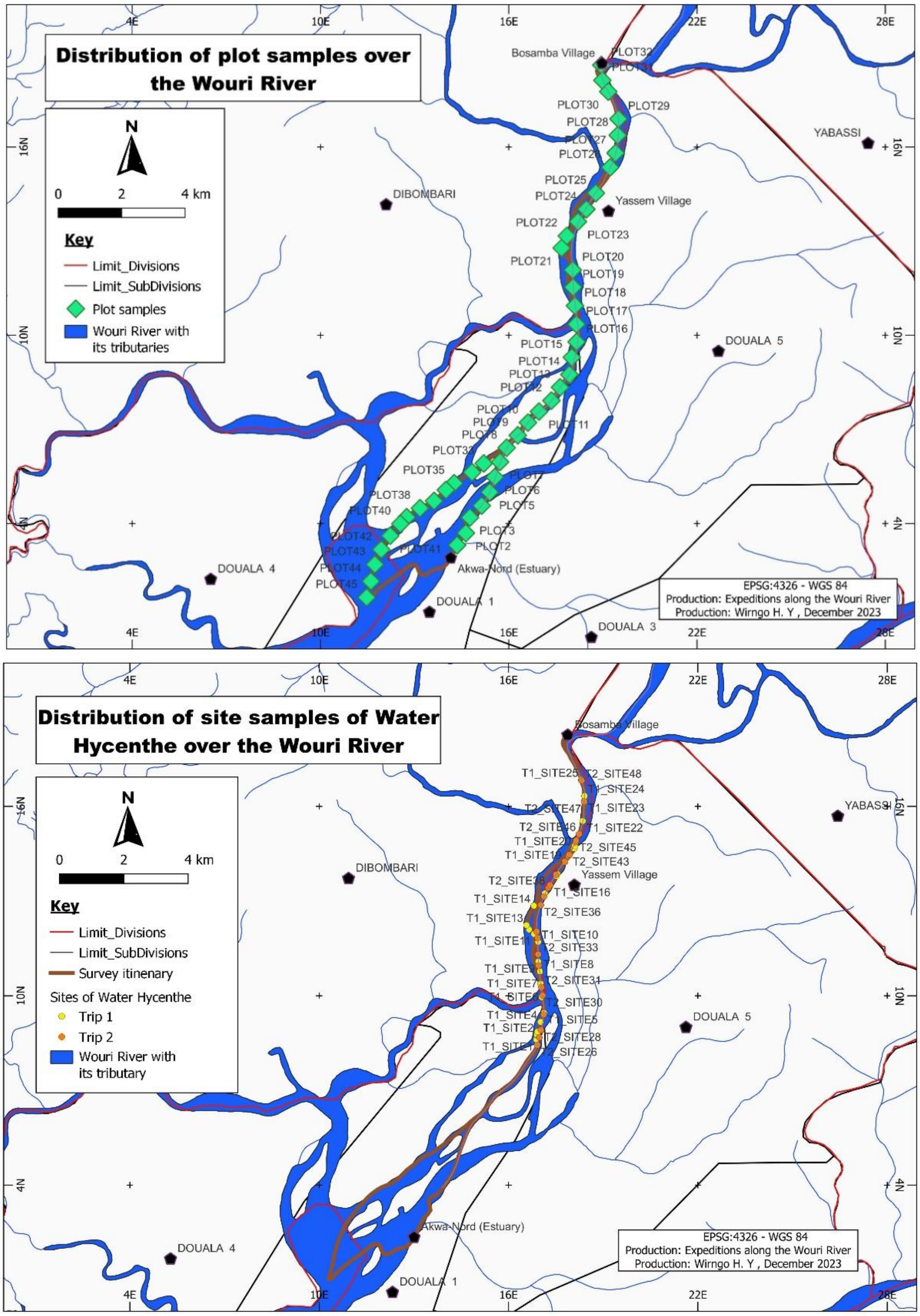

Fig. 2 Distribution of water hyacinth sampling plot and sites in River Wouri over the 19.5 km stretch from Akwa North to Bossamba village in the dry and rainy season in 2023

Fig. 3 Field survey on the quantity of water hyacinth along the River Wouri over the 19.5 km stretch from Akwa North to Bossamba village in 2023

Table 1 Satellite image description over River Wouri, Douala (1982- 2022)

Description	Sensor	Acquisition Date	Cloud Cover	Projection System	Resolution (m)
LT05_L1TP_186057_19821221_20170215_01_T1	Landsat LT05	21-12-1982	13%	WGS 84	30
50813420312290959462J0	Spot HRV 1	06-1992	2%	WGS 84	10
40803410101021007042I6	Spot HRV 3	02-05-2002	3%	WGS 84	10
LE07_L1TP_186057_20120105_20200913_02_T1	Landsat LE07	05-01-2012	8%	WGS 84	30
LC08_L1TP_186057_20221221_20211229_02_T1	Landsat LC08	21-12-2022	5%	WGS 84	30

Data Processing and Analysis

The data from the GPS was download and entered into excel before exporting it into ArcGIS. Maps were generated to show the distribution of water hyacinth at various sampling locations. The quantity of water hyacinth in each location was calculated. The results were display in histograms showing the difference in rainy season and dry season distribution of water hyacinth. The acquired satellite images were processed and analysed using ENVI software, version 5.3 which is specialized for remote sensing data. The analyses followed a systematic approach involving five stages :

1. **Band Assembly:** The spectral bands for each satellite image were assembled to form composite images. This step is critical for subsequent analysis, ensuring that all relevant spectral information is available for interpretation.
2. **Vegetation Index Generation:** Vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), were calculated for each year. These indices are essential for assessing changes in vegetation cover over time, providing insights into environmental and land use changes.
3. **Spectral Signature Analysis:** Spectral signatures were extracted and analysed to distinguish between different land cover types. This step involved identifying the unique spectral characteristics of various surfaces, such as forests, water bodies, and urban areas.
4. **Region of Interest (ROI) Demarcation:** ROIs were delineated based on ground truth points collected during field surveys. This step ensured that the classification was accurate and reflected the actual land cover on the ground.
5. **Supervised Classification:** A supervised classification technique was applied to categorize the land cover into predefined classes, including buildings/bare ground, forest, water bodies, mangroves, and a specific land use class named Jacintha. This classification was validated using the collected ground truth data to ensure accuracy.

After classification, the data were transferred to QGIS, a GIS software, for further analysis. In QGIS, area measurements were conducted for each land cover class, and thematic maps were produced to visualize spatial distribution and temporal changes.

RESULTS AND DISCUSSION

Seasonal distribution of water hyacinth in River Wouri in 2023

Figure 4 and 5 illustrate water hyacinth coverage in River Wouri over 46 locations and 26 sites demarcated along 19.5 km of the distance covered.

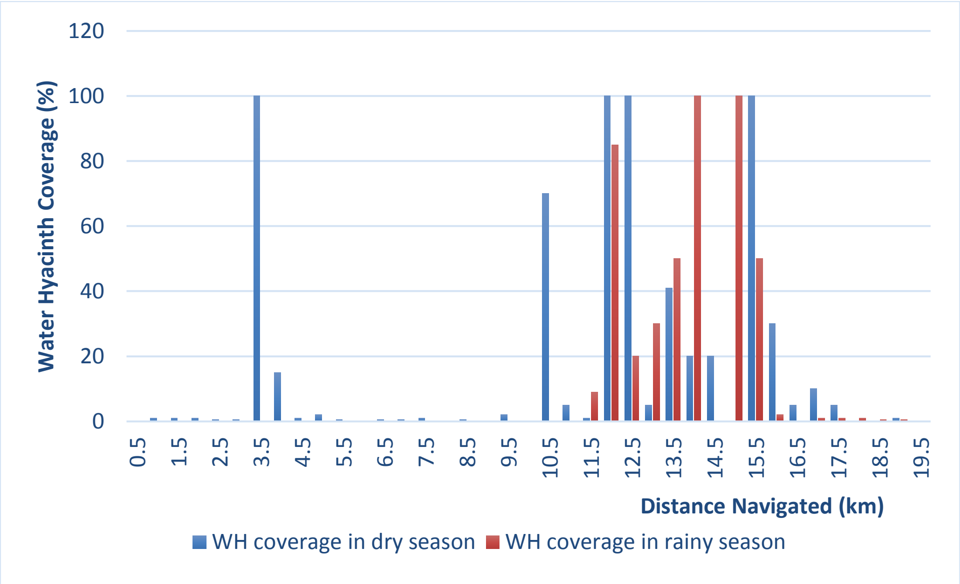

Fig. 4 Seasonal distribution of water hyacinth sampling plots in River Wouri over the 19.5 km stretch from the Wouri Bridge to Bossamba village in the dry and rainy season in 2023

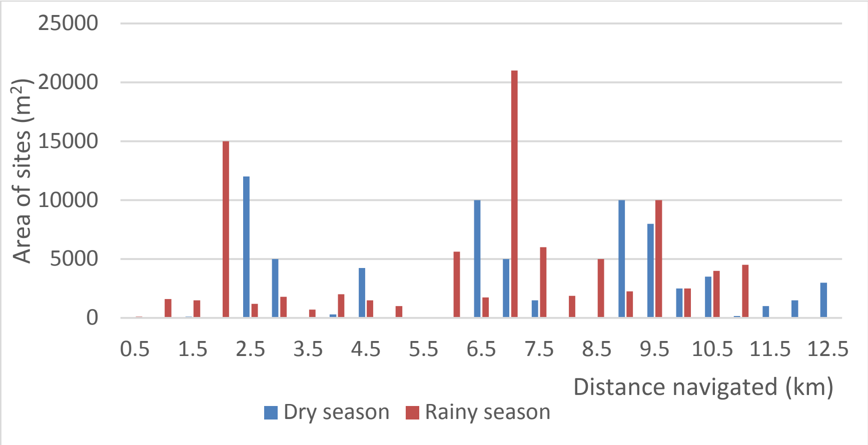

Fig. 5 Area coverage of water hyacinth sampling sites in River Wouri over the 19.5 km stretch from the Wouri Bridge to Bosamba village in the dry and rainy season in 2023

Two main observations were made when a comparison was made in the results obtained for the distribution of water hyacinth in sampling plots (20 X 20 m^2) for both seasons. The first is that, water hyacinth in found in River Wouri all year round in the dry and the rainy seasons. However, the second observation was that, the spread (siting / occurrence) of water hyacinth in the dry season far outweighs the spread in the rainy season. The primary reason for a higher degree of spread in the dry season over the rainy season is the River flow rate / turbulence which is greatly influenced by rainfall frequency and intensity.

Water hyacinth thrives in stagnant water bodies than flowing river. Hence, the condition during the dry season when the flow of River Wouri is more stable promotes rapids proliferation of the weed. Increased runoff into River Wouri and high turbulence during the wet seasons accounted for drastic drop in the distribution of water hyacinth in sampled plots. Fast moving waters cut off and carry off water hyacinth patches and this is the reason why the population of water hyacinth in most of the plots had disappeared or occupy less than 1% of the sampling plots compared (Figure 4). The benefit of this knowledge is that, water hyacinth eradication schemes are recommended immediately after the peak of the wet season when nature has taken care of most of the problem.

The final observation was that, as we navigated from the anterior to exterior end of river Wouri, (at least 10 km away from the main bridge on national road), the population of water hyacinth generally increased. This is probably due to the influence of human activities such as industrial activities that release chemical substances not conducive for the spread of weed. The highest area occupied by water hyacinth was approximately 21 000 m^2 in the rainy season and 12 000 m^2 in the dry season (Figure 5). The present study shows that the growth of water hyacinth in River Wouri is greater during the dry season than the wet season, on the contrary, there have been studies showing that the spread of this weed is dominant in the rainy than in the dry season (Dube et al., 2017; Thamaga & Dube, 2019).

Table 2 Spatial-temporal distribution of water hyacinth in River Wouri from 1982 – 2022

	1982		**1992**		**2002**		**2012**		**2022**	
Land cover	Area(ha)	(%)	Area(ha)	(%)	Area(ha)	(%)	Area(ha)	(%)	Area(ha)	(%)
Settlement	87.7	0.68	116.81	0.91	255.45	1.99	256.88	2.00	421.72	3.28
Other vegetation	6598.27	51.39	6556.84	51.03	6925.56	53.85	7834.7	60.88	8235.8	63.99
Mangrove	2513.09	19.57	2528.52	19.68	1970.94	15.33	979.76	7.61	450.94	3.50
Water body	1642.73	12.79	1642.73	12.78	1702.55	13.24	1751	13.61	1702.8	13.23
Water hyacinth	16.23	0.13	13.13	0.10	3.42	0.03	35.71	0.28	36.74	0.29
Total	12840.02	100	12850	100	12859.92	100	12870	100	12870	100

ha: hectares

Table 2 shows the changes in the land cover around River Wouri in Douala from 1982 to 2022. The trends observed from the table was as follows. For the settlement area, the area occupied increased by 334.02 ha (that is from 87.7 to 421.72 ha). The percentage of land covered by settlements grew from 0.68% in 1982 to 3.28% in 2022. This increase indicates a significant expansion in urban development in the area. Water hyacinth distribution showed an overall increase in the area covered but remains relatively small. The area increased by 20.51 ha from 16.23 to 36.74 ha respectively from 1982 to 2022. The percentage of total land area occupied by water hyacinth rose slightly from 0.13% to 0.29%, showing a minor but persistent rise increase

The next category was mangrove which showed a mark decrease in area occupied. The mangrove cover dropped by 2062.15 ha from 2513.09 in 1982 to 450.94 ha in 2022. The percentage coverage fell from 19.57% to 3.50%, indicating a severe reduction in mangrove ecosystems over the years. A significant loss in mangrove area, possibly due to environmental changes and human activities was observed. As for the water body, the area covered by water bodies remained relatively stable with a slight increase. That is, it varied slightly from 1642.73 ha (12.79%) in 1982 to 1702.8 ha (13.23%) in 2022, showing minimal change of 60.07 ha increment. The next category other vegetation apart from mangrove and water hyacinth. There is a steady increase in the area covered by other vegetation. The trend was an increase by 2637.53 ha from 6598.27 in 1982 to 8235.8 ha in 2022. It rose from 51.39% to 63.99% indicating an increase in vegetative cover which can be accounted for by agricultural practices as a result of increased settlements.

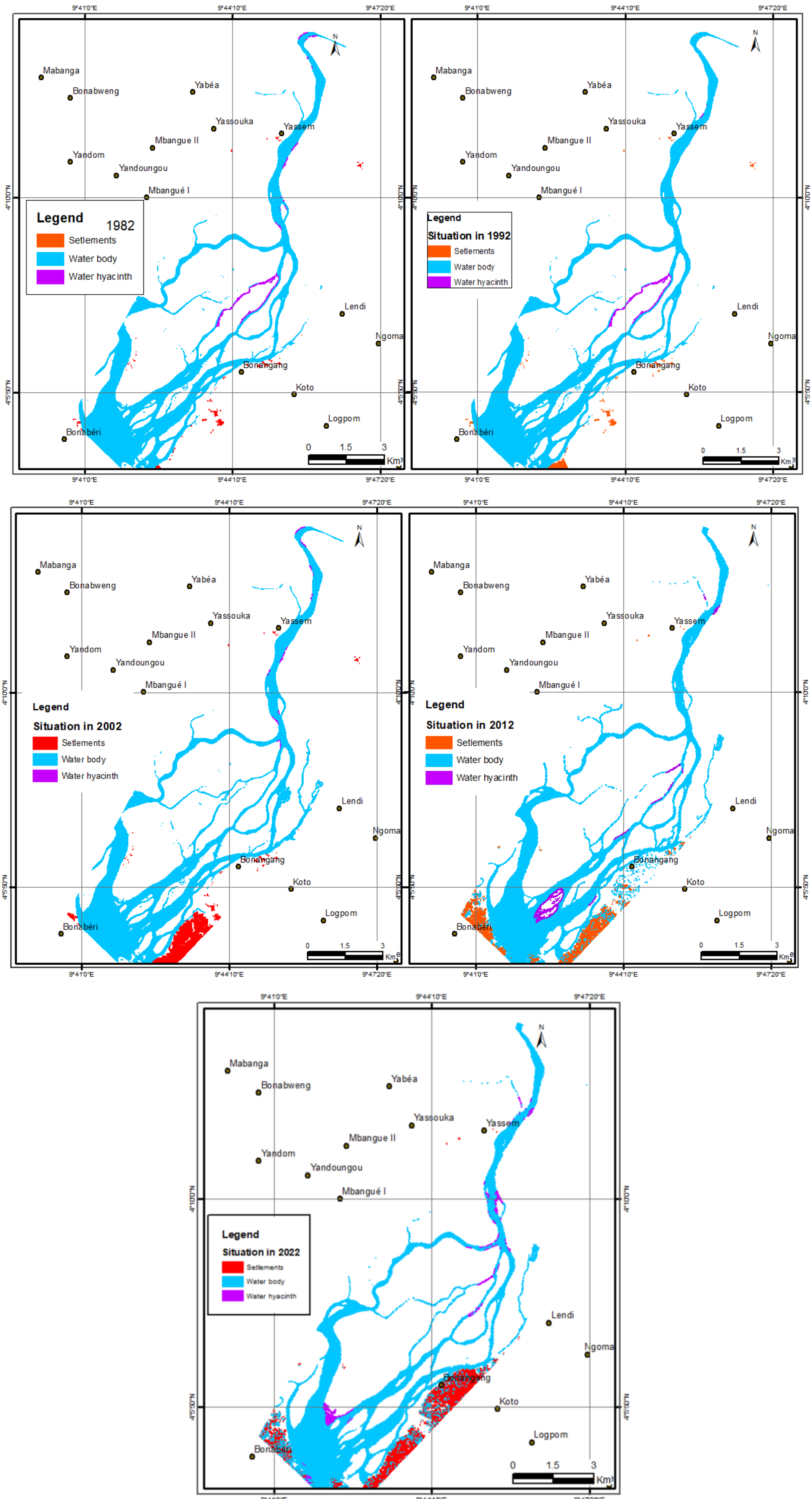

Fig. 6 Spatio-temporal distribution of water hyacinth in river Wouri, Douala (1982 – 2022)

Trends in the land cover changes in river Wouri (1982- 2022)

Figure 6 depicts the changes in the distribution of water hyacinth in river Wouri over 40 years from year 1982 to 2022. From 1982 to 1992, the area covered experienced an urban growth, which was manifested by settlement areas growing by 0.23%. In contrast, other vegetation experienced a slight loss in vegetative cover decrease of 0.36 %. The Mangrove areas showed minimal decrease of 0.10%. However, water bodies decrease slightly (only 0.01 %) but there were insignificant changes in water hyacinth coverage.

The changes from 1992 to 2002 showed that settlement areas increased by 1.08%, suggesting increasing urban expansion. Other vegetation grew by 2.83%, indicating an increase in vegetative coverage. In contrast, mangrove areas fell drastically by 4.35%, indicating a severe loss or deterioration of mangrove habitats which is a consequence of urban expansion. Water bodies experienced a minor increase of 0.46 %, displaying little growth. Water hyacinth coverage dropped by 0.08%. Overall, this period was marked by strong urban growth, increase in other vegetation, massive loss in mangrove, and a modest expansion of water bodies.

The period between 2002 and 2012 showed a similar trend to the last decade with settlement areas increasing by 0.01% due to constant urbanization. Other vegetation had a 7.02% increase which was the highest in vegetative cover of the 4 decades. Mangrove areas continued to decrease substantially by 7.71%, indicating a significant loss of mangrove habitats (almost 2 times the loss in the previous decade). Water bodies witnessed a 0.37% increase and water hyacinth coverage increased by 0.25% which was the period with highest increase in its presence. Overall, this period saw relative stable growth in settlement areas, substantial growth in other vegetation, continuous severe mangrove loss, a minor increase in water bodies and water hyacinth coverage.

The last decade assessed (2012-2022) showed that settlement areas expanded by 1.28% between 2012 and 2022, demonstrating constant urbanization. Other vegetation increased by 3.12% indicating a continued increase in vegetative cover. Mangrove regions experienced another significant 4.1% (similar to that of 1992 -2002), implying more habitat degradation. Water bodies decreased by 0.37%. Water hyacinth coverage increased by 0.01% showing small increase in its presence. Trend in the area coverage in this decade can be summed up into increase settlement (major urban growth), increased vegetative cover, significant mangrove loss, a little drop in water bodies, and a slight increase in water hyacinth.

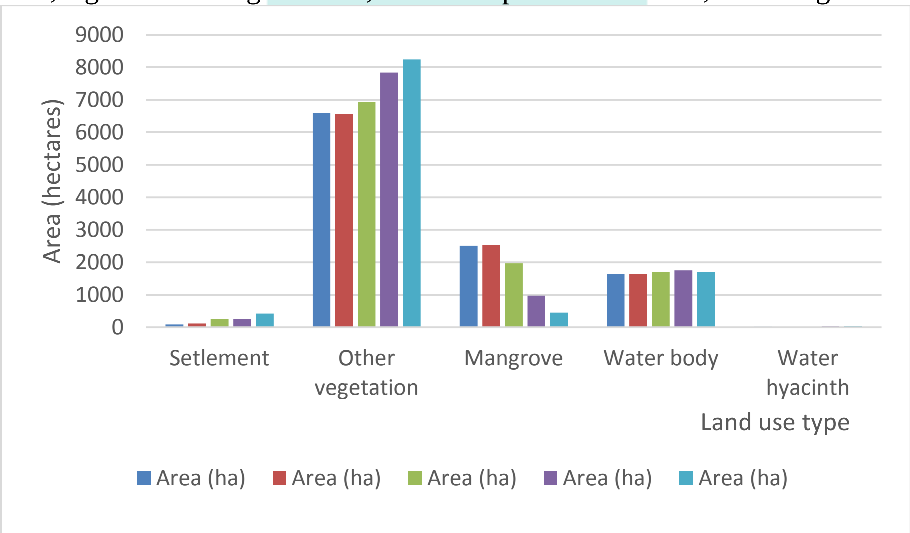

Fig. 7 Overview of the area (ha) of different land use types in Wouri over 40 years.

The area coverage of water hyacinth in the past 4 decades is not significant (based on hectares occupied) when compared with the coverage of settlement area, other vegetation, mangrove, and water body (Figure 7). However, in the past 40 years water hyacinth occupied approximately 0.13%, 0.10%, 0.03%, 0.28% and 0.29% of River Wouri respectively in 1982, 1992, 2002, 2012 and 2022 (Figure 8). The year 2002 was the year with least coverage (probably as a result of government intervention in trying to eradicate the weed) while 2012 and 2022 had the highest coverage of water hyacinth (probably as a result of recurrence and regeneration of dormant seeds.

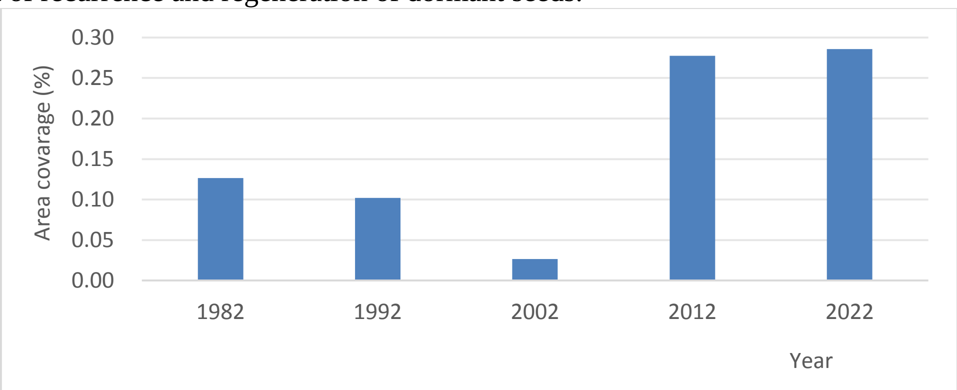

Fig. 8 Overview of the water hyacinth coverage (%) in Wouri in the last 40 years (1982-2022)

CONCLUSION

The seasonal distribution of water hyacinth showed an increase coverage in the dry season than in the rainy season in the year 2023. From 1982 to 2022, the changes in land use land cover shows a general increase in settlement (urban expansion), increasing vegetative cover, significant loss of mangrove areas, stable water bodies, and a modest rise in water hyacinth coverage. Settlement areas have steadily increased over the decades, with significant increases from 1982 to 2022, showing continued urbanization. The size of water bodies remained mostly consistent, with small fluctuations, indicating that infestations of water hyacinth covering did not alter much. Water hyacinth coverage increased marginally, with a significant growth from 2012 to 2022, indicating progressive increase. Effective water hyacinth eradicate schemes should be planned and executed immediately after the peak of rainy season when runoff and increased river flow/ turbulence have carried off most of the weed.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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