IDENTIFICATION AND MAPPING OF ESSENTIAL FISH HABITATS USING REMOTE SENSING AND GIS CASE STUDY LAKE VICTORIA

by

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Project report submitted to the department of Geomatic Engineering and geospatial Information Systems degree of Bachelor of Science in Geospatial Information Science.

Department of Geomatic Engineering and Geospatial Information Systems (GEGIS)

DECLARATION

I declare that this project is my own work and has not been submitted by anybody else in any other university for the award of any degree to the best of my knowledge.

Sign………………………………… Date…01/02/2021…………

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CERTIFICATION

This project has been submitted for examination with my approval as the candidate's supervisor.

Sign……………………… Date ……01|02|2021…………………

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Acknowledgements

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Abstract

Fisheries in Lake Victoria have been threatened by declining fish stocks and diversity, environmental degradation due to increased input of pollutants, industrial and municipal waste, overfishing and use of unapproved fishing methods, infestation by aquatic weeds especially water hyacinth, de-oxygenation and a reduction in the quantity and quality of water. Remote sensing and GIS are essential tools in detection of fishing grounds which is important in providing fish sustainability for human being. This recent tool allows fishing grounds detection at minimal cost and optimizes effort. This research tends to identify the most favourable both environmentally and ecologically satisfactory factors which favours fish breeding and growth. Landsat 8 derived satellite data of Chl-a and lake surface temperature (LST) and fisheries catch data were analyzed using suitability index (SI) in Lake Victoria. Distribution of fish was associated with preferred range. Potential fishing ground maps derived from the SI. This project attempts to justify the application of satellite imagery as a tool to identify, map and forecast the parameters which are linked to fish presence in aquatic environments. The study concentrated on establishing suitability ratings in different parts of Lake Victoria using lake surface temperature and chlorophyll-a levels. The study was conducted for months; January, May and December 2019 on Lake Victoria.

The output obtained illustrated the availability of suitable and habitable zones within the lake using satellite imagery and the suitability index. The fish catch data and satellite derived variables are used to determine habitat suitability indices for fish during January, May and December 2019. More than 90% of the total catch was found to come from the areas with sea surface temperature of 23.0°–28.3°C and chlorophyll-*a* concentration 0.72–1.31 mg/m^3 and the catch data was used to validate the images. This study indicated the capability of HSI as a tool to map the potential fishing grounds of fish species in Lake Victoria. The potential fishing zone maps will help the fishers and fishery management to identify the extract zones in lake and manage resources.

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Acronyms and abbreviations

CPUE	Catch per Unit Effort
PFZ	Potential Fishing Zone
KMFRI	Kenya Marine and Fishing Research Institute
Chl-a	Chlorophyll-a
DN	Digital Number
FLAASH	Fast-line-of-sight atmospheric analysis of spectral hypercubes
PA	Parachute boat
SMS	Sesse Mortorized/Sail
SP	Sesse Paddled
BoS	Boat Seine
BS	Beach seine
CN	Cast net
GN	Gillnet
HL	Hand Line
LL	Long line
SS	Small seine
SN	Set net
TR	Trap

1 Introduc

1.1 Background

Lake Victoria supports the largest inland freshwater fish
African Countries: Kenya, Uganda and Tanzania. It has a s
(6%), Uganda (43%) and Tanzania (51%). The Kenyan por
portion produces the bulk (80%) of the country's annual
diversity of over 500 species of fish most of which were
perch and tilapiine cichlids, coupled with over exploitatio
species have since disappeared from the lake (El-Sayed,
are *Rastreonobola agentea* (Omena/dagaa/mukene) 53
and *Oreochromis niloticus* (Tilapia) 4.31%. Fish stocks
proliferation of invasive species, over-fishing and use of il

Ecological processes at various temporal and spatial scales mechanisms regulating species and habitat distributions (Guisan and Thuiller 2005, Kozak et al. 2008, Elith and Leathwick 2009). For example, Moore et al. (2009) studied the relationship between seascape features and an assemblage of demersal fish species and were able to predict their distribution in a marine national park, results that are directly applicable in marine spatial planning. These types of studies can increase our understanding of the processes behind distribution patterns and simultaneously provide scientific advice for management.

1.2 Motivation and problem statement

Management needs, and should, be based on best available scientific principles. Since management of human activities in water systems inherently require spatial approaches (Rice 2005), science needs to meet this demand. Maps of habitats and ecological communities are needed for an efficient management of the heavily exploited zones in the lake. Knowledge on the spatial extent of essential habitats for fish and other organisms is however sparse. This research is expected to show, predictive spatial modelling together with field studies to provide a powerful approach to obtain maps of important fish reproduction areas, results that are directly applicable in fresh water management. The underlying concept that a variety of well-defined habitat characteristics are needed to host certain species, assemblages or communities is reflected in the use of networks of protected areas aimed at conservation of specific habitat types, such as the marine Natura 2000 network in Europe. A spatial approach can in this context serve dual purposes, as to be demonstrated in this research by mapping habitat distributions and by developing tools for evaluation of network performance. Spatially explicit research thus forms an integral role in developing approaches to evaluate and advice conservation management aimed at ecologically important habitats. However, habitat science and nature conservation have traditionally been separated from fisheries science and management (Rice 2005, Armstrong and Falk-Petersen 2008). As management and policies are moving towards integrated and ecosystem-based considerations, an increased understanding of the effects of habitat availability and quality on fish population sizes and dynamics is highly needed. To summarize, species distribution modelling provides a powerful tool for identification and mapping of ecologically important species and habitat distributions that are highly relevant for an integrated and ecosystem-based management of marine resources.

1.3 Research identification

1. The main aim of this research is to identify and map the essential fish habitats. This is achievable through the following specific objectives:

1.3.1 Research objectives

1) To identify the habitat variables that promote fish breeding
2) To extract surface temperature, chlorophyll-a from satellite imagery.
3) To determine potential fishing grounds using Suitability Index (SI).

1.3.2 Research questions

The following questions are formulated with respect to aforementioned objectives:

1) Which factors or variables affects fish breeding in fresh water environment?
2) What are the possible fish habitats?

1.4 Study outline

This study aims to illustrate how remotely sensed variables and fishing operations data can be used to predict suitable habitat of fishery resources in Geographic Information System. Lake surface temperature (LST), chlorophyll concentration (Chl-a) as predictor variables. Fishery data for study period were segregated randomly to create training and validation. Catch was normalized into Catch per unit Effort. Generalized additive modelling was performed on training data and then tested on validation data. Suitable ranges of LST, Chl-a for species distributions were derived and integrated to predict their spatial distributions.

Literature review

This is related to the following studies that have been performed by different sectors in Lake Victoria.

i. **Assessment of the Lake Victoria Nile perch slot size and dissemination of the findings for better management of the fisheries.**

Nile perch from Lake Victoria provides important export earnings for riparian communities. However, concerns about over-exploitation of the stock have been raised with recent studies showing signs of overfishing, such as a decline in catch rates and a decrease in size at first maturity. The decline trend has progressed un-abated despite the slot regulation that was supposed to ensure sustainable exploitation of the fishery. This study sought to assess the dynamics of the Nile perch fishery amid the slot size regulation. Nile perch size structure and maturity information were obtained from both experimental fishing (trawl) and commercial landing data obtained variously from the year 2011 to 2017. Results show that the Nile perch population is dominated (73%) by individuals that are < 50 cm TL. About 26% lie within the recommended slot size of 50 – 85 cm. Less than 1% of Nile perch are > 85 cm TL. Further, results show the size at 50% maturity (Lm50) for males is currently 52 cm TL, indicting the rationale of having the lower slot size limit at 50 cm. The Lm50 for males showed a significant reduction within the last decade probably responding to overfishing. The effect of the regulation on the population structure needs further investigation since slot size and gear restrictions don't limit the number of fish caught. A shift from size and gear restriction to allowable (control of outputs) is recommended. This study utilized data collected in various trawl surveys undertaken in Lake Victoria from the years 2011 to 2017 and from commercial landings of the lake collected in the years 2015 and 2016. Historical life history information for Nile perch was, derived from secondary sources (i.e. publications and previous regional and national surveys). The following conclusions were made based on the research:

Nile perch is dominated by individuals less than 50 cm TL. It implies fishes around 30—40 cm (1—year class) are not crossing at all, into other year (or big size) classes, which is highly unexpected. This could be attributed either to prey deficit, where Nile perch may suffer high natural mortality beginning from around 25—30 cm TL as they switch from Caridina-dominated diet to Haplochromine—dominated, or intensive fishing as the fish begin to cross into the slot size. These two hypotheses need to be explored adequately. Males dominate the adult sex ratio. This might be a consequence of applying disproportionate pressure on females, which generally grow to bigger sizes than males, occasioned by the slot size regulation. Selection bias of fleet against one sex might alter the population structure of the species which could have adverse effect on the sustainability of a fishery. Disturbing the natural sex ratio may compromise the reproductive potential of a fishery.

Generally, over the years, the Lm50 value for Nile perch has been showing gradual decrease an indication of increased fishing pressure. A drastic decrease of the spawning stock proportion is evident after the slot size regulation was established. While we continue to enforce the slot size regulation, the effect of the regulation on the population structure needs further investigation as recommended below.

How the study or project fits with previous research in that discipline or topic area.

ii. **Factors influencing water hyacinth's and their spatio-temporal distribution in Lake Victoria for dissemination of the findings**

Invasive aquatic water hyacinth, *Eichhornia crassipes* in Lake Victoria have exhibited a periodic cyclic pattern of disappearance and proliferation with its attendant ecological and economic concerns. This study aimed to monitor the factors influencing water hyacinth distribution in Lake Victoria in order to establish their impact on fisheries. The study employed a combination of remote sensing and Geographical Information System (GIS) techniques to provide coverage estimation of water hyacinth. ERDAS 13 software was used to process Landsat 8 satellite images while ArcGIS 10.0 was used to produce maps and compute the macrophyte extent fortnightly. Data on fish landings and their respective market values were acquired from the Electronic Fish Market Information Service (EFMIS) database, hosted at Kenya Marine and Fisheries Research Institute (KMFRI). Analysis of consistent temporal satellite data showed areas frequently covered by the weeds included sheltered bays and river mouths that depended on wind pattern and water currents. Nyanza gulf had higher coverage (averagely 5,000 ha) of macrophytes compared to the open waters (<200 ha). The study proposes the need for sustained monitoring of the water hyacinth alongside minimization of nutrient loading impacts on the fishery, especially with the opening of Mbita causeway.

iii. **Catch Assessment Survey Report in Lake Victoria, Kenya to disseminate the findings.**

The report provides information on species composition, estimates of mean catch rates in kg boat-1day-1, total catches in metric tons; values of Nile perch (*Lates niloticus*), dagaa (*Rastrineobola argentea*), Nile tilapia (*Oreochromis niloticus*) and other fish species caught in Lake Victoria, Kenya, as well as population structure of Nile perch. The main craft gear combination for the main target species (Nile perch, tilapiines, dagaa and haplochromines) are also presented. Total catch was estimated at 19,310.9 metric tons for May 2018, comprising of dagaa (81.8%), Nile perch (16.0%) and tilapiines (1.1%), while the remaining species, haplochromines, *Synodontis spp* (*Clarias gariepinus, Protopterus aethiopicus)*, *Bagrus spp* and others combined together contributing the remaining percent. Nile perch catches were high from long lines and gillnets using boats propelled by either motor or sail which operated in offshore waters and beach seines using sesse paddled boats. Homa Bay County recorded the highest proportion of fish landed in quantity (49%) and value (48%). Tilapiines were caught mostly with gillnets followed by hand lines. Fishers also used gears such as cast nets operated also in areas close to the shore or within the bays. Hand line hooks using parachute boats and small mesh gillnets are operated in the near shore waters. There has been a decrease in overall contribution of tilapia to total catches from (7%), in November 2005 to (1.1%) in the current, May 2018 survey. The total value of the catch was estimate d at Ksh.1.2 billion (U$12,154,667).

In terms of value, Nile perch was leading 58.9 % of the total estimated value while dagaa contribution was 35%. Tilapia is valued as well, though its contribution was only 5%. Through these CASs, information is building up to show the new picture of fish production in the Kenyan waters of the lake, however, precautionary approach should be taken in the proper management intervention to ensure its sustainability of tilapia fishery. Haplochromines are caught as a bycatch along with light attracted dagaa and by same seine nets during day and moonlights. There is need to investigate the effects of day and moon light fishing using small seines on haplochromine stocks.

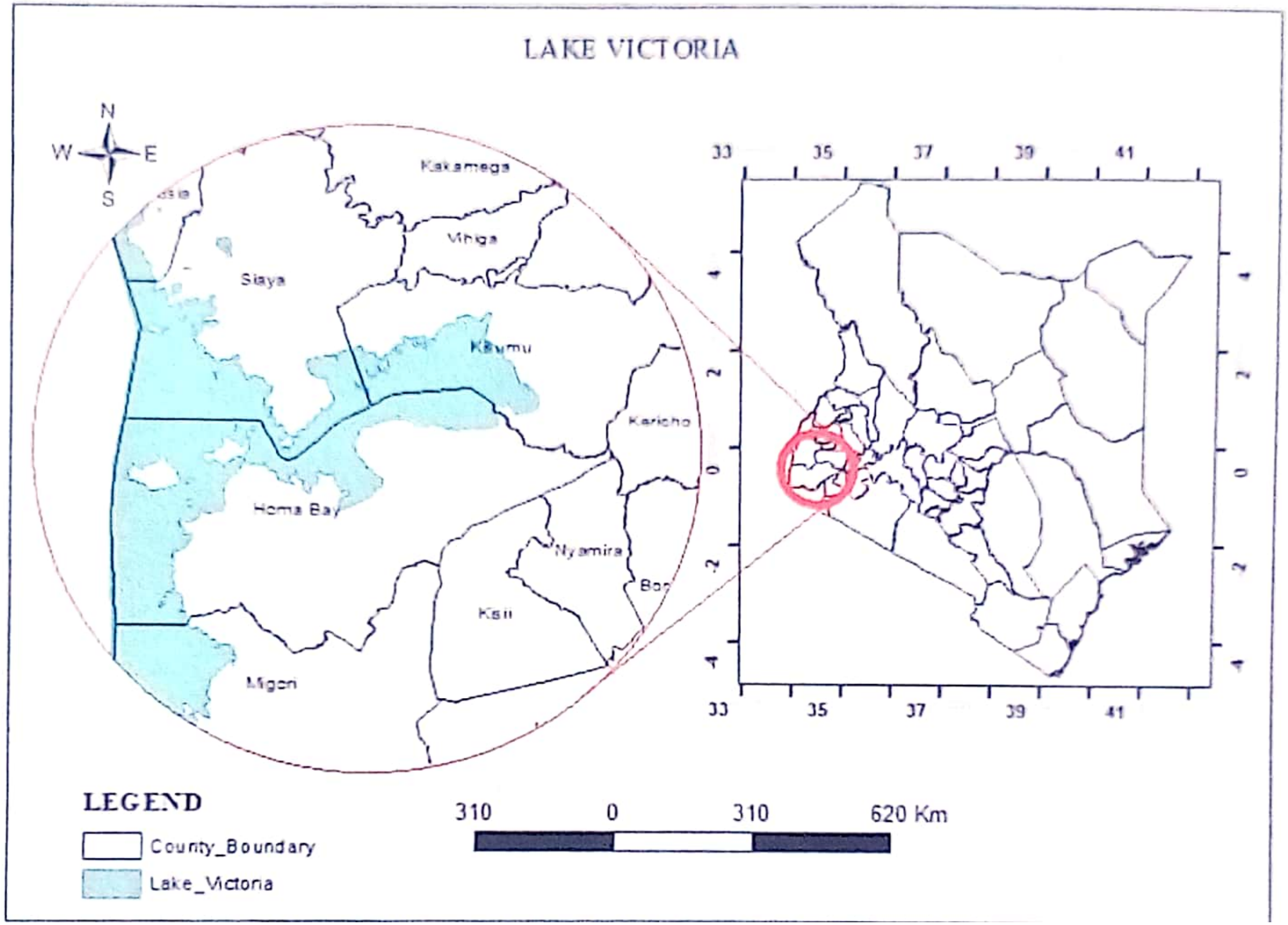
Materials and methods

1.5 Study area

Position and size

Lake Victoria traverses the three East African Countries: Kenya, Uganda and Tanzania. It lies within longitudes 33° 52' 55'' and 35° 00' 45'' East and latitudes 0° 22' 42'' North and 1° 00' 34'' South. It has a surface area of 68,500km² shared between Kenya (6%), Uganda (43%) and Tanzania (51%). The Kenyan portion of the lake covers an area of 4128 km².

The climate in the lake basin varies from tropical rain forest with rainfall over the lake for much of the year to a semi dry climate with intermittent droughts over some areas.



LAKE VICTORIA
N
W
E
S
Kakamega
Vihiga
Siaya
Kisumu
Kericho
Homa Bay
Nyamira
Kisii
Migori
33 35 37 39 41
4 2 0 -2 -4
LEGEND
County_Boundary
Lake_Victoria
310 0 310 620 Km

1.6 Data

Two types of data were used;

- Satellite imagery data, Landsat 8 – USGS
- Fishery data- (position, net size, catch weight)

Data type	**Sensor**	**Band**	**Wavelength (μm)**	**Resolution (m)**	**Use**
Satellite image	Landsat 8	Band 2	0.45-0.51	30	Chlorophyll-a extraction
		Band 3	0.53-0.59	30	Chlorophyll-a extraction
		Band 4	0.64-0.67	30	Chlorophyll-a extraction
		Band 5	0.85-0.88	30	Chlorophyll-a extraction
		Band 10	10.6-11.19	100	Lake surface temperature extraction
		Band 11	11.5-12.51	100	Lake surface temperature extraction
Fishery data	———	———	———	———	PFZ map

1.7 Methodology

The overall methodology is shown below;

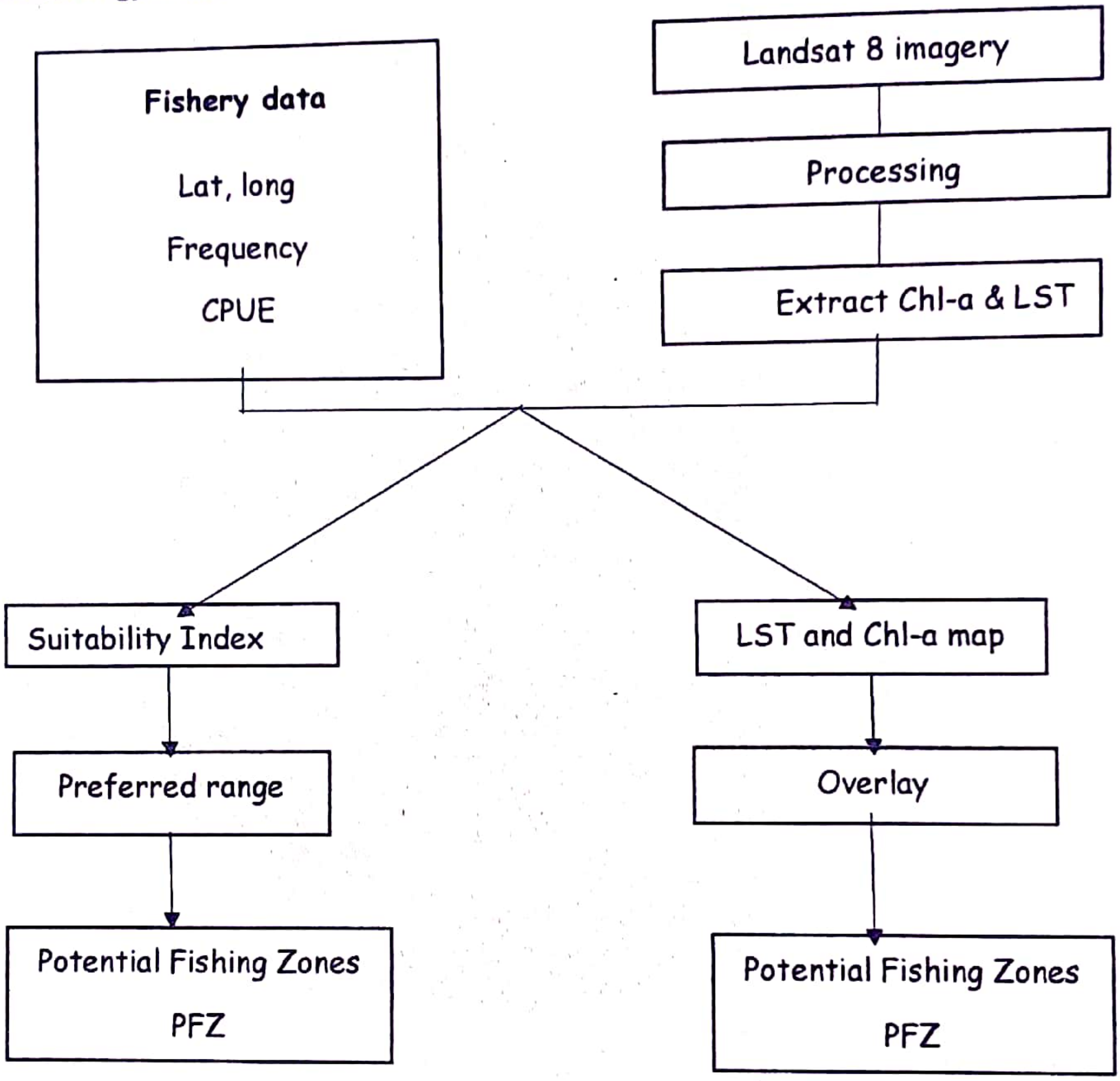
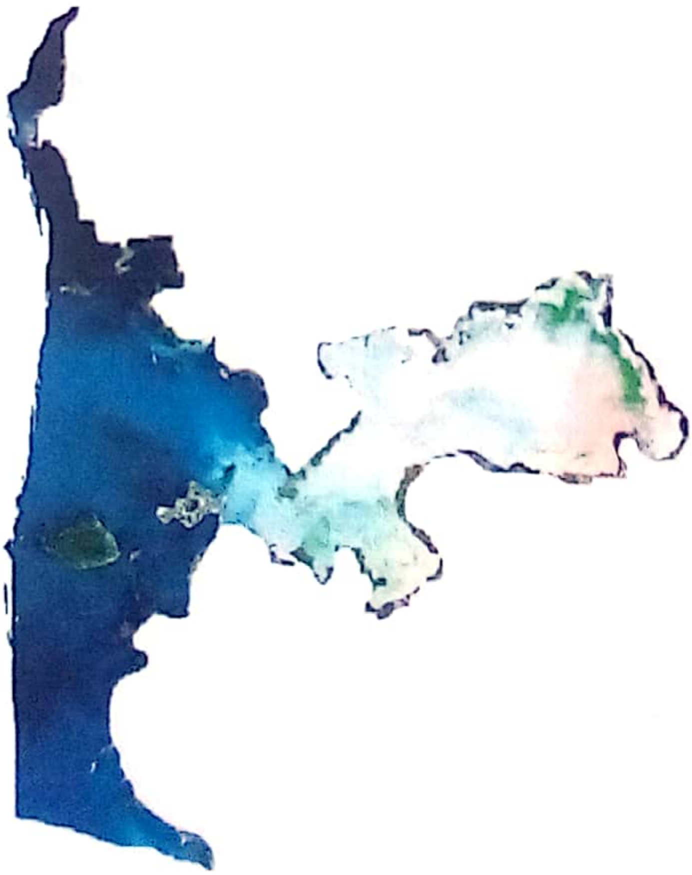


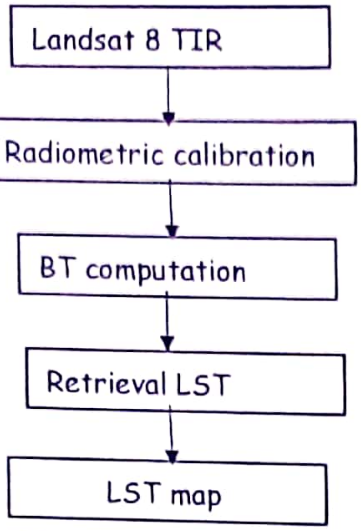
Figure: Workflow

From the chart above; the satellite image was imported, reprojected to change the projection to UTM. Subset was extracted to obtain area of interest or region of interest (subset image). Image correction such as radiometric calibration, atmospheric correction for cloud filtering, then lake surface temperature and Chlorophyll-a were extracted from the image.

Fig.2: Landsat 8 image Jan 2019.



1.7.1 Surface temperature extraction



The estimated data was obtained by the Landsat 8 Thermal Infrared Sensor (TIRS). Landsat 8 provides metadata of the bands such as thermal constant, rescaling factor value,

Thermal constant	Band 10	Band 11
K1	774.8853	480.8883
K2	1321.0789	1201.1442

Table.1 showing K1 and K2 value

Rescaling factor	Band 10	Band 11
M_λ	0.00033420	0.00033420
A_λ	0.10000	0.10000

Table.2 rescaling factor

First, the digital number (DN) of band 10 and band 11 had to be converted to radiance by using following formula;

$$L_\lambda = M_\lambda x Q_{cal} + A_\lambda$$

Where

L_λ, is the top of the atmosphere spectral radiance,

M_λ is band specific multiplicative rescaling factor,

Q_{cal} is digital number, and

A_λ is the band specific additive rescaling factor.

(United States Geographical Survey, 2013)

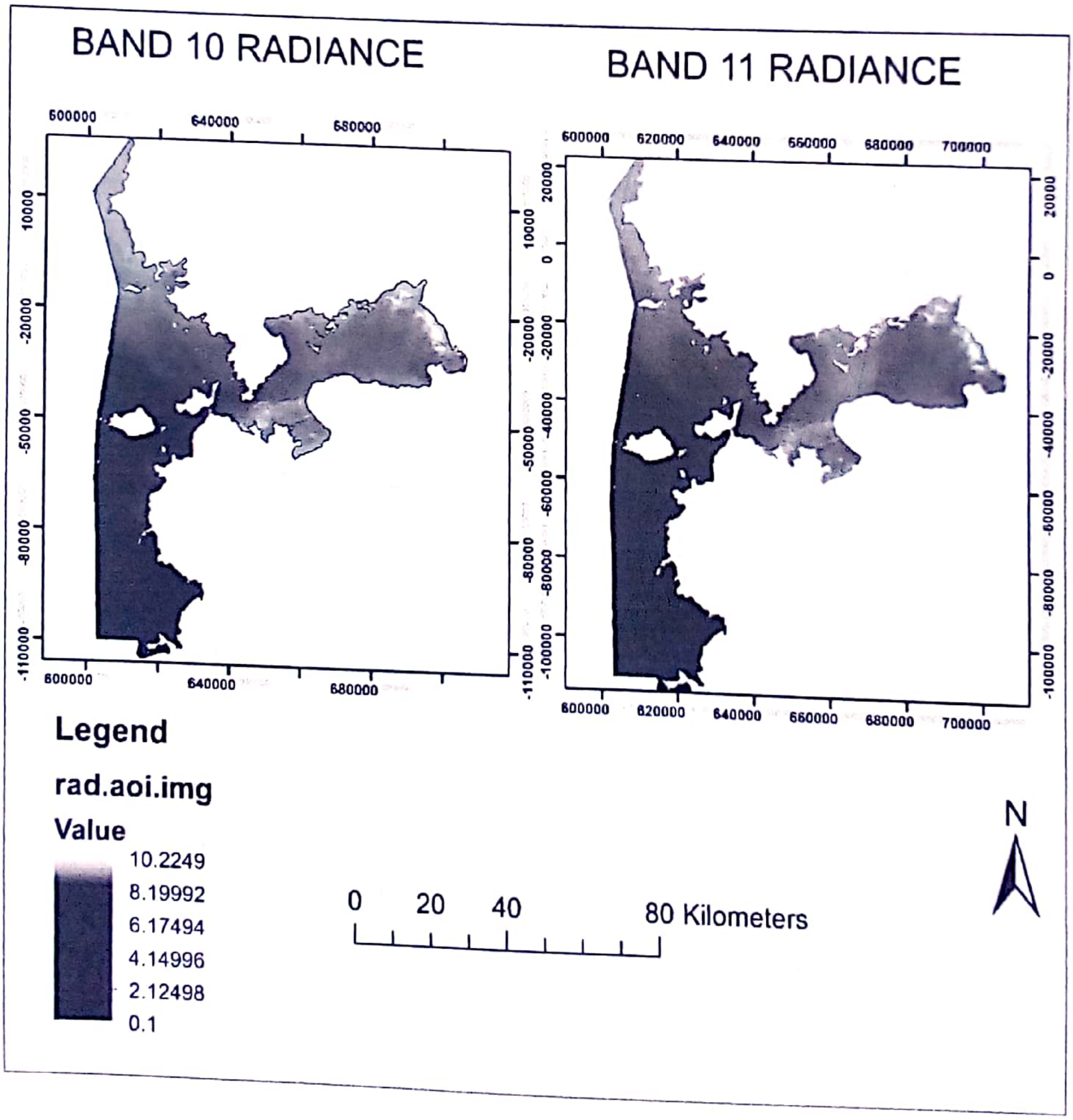


Fig.4: Radiance.

Then, converted them to the brightness temperature by using this formula;

$$T = \frac{K2}{\ln\left(\frac{K1}{L_\lambda} + 1\right)}$$

Where T is at satellite brightness temperature (Kelvin), K1 and K2 are thermal conversion constants from metadata. (United States Geological Survey, 2013)

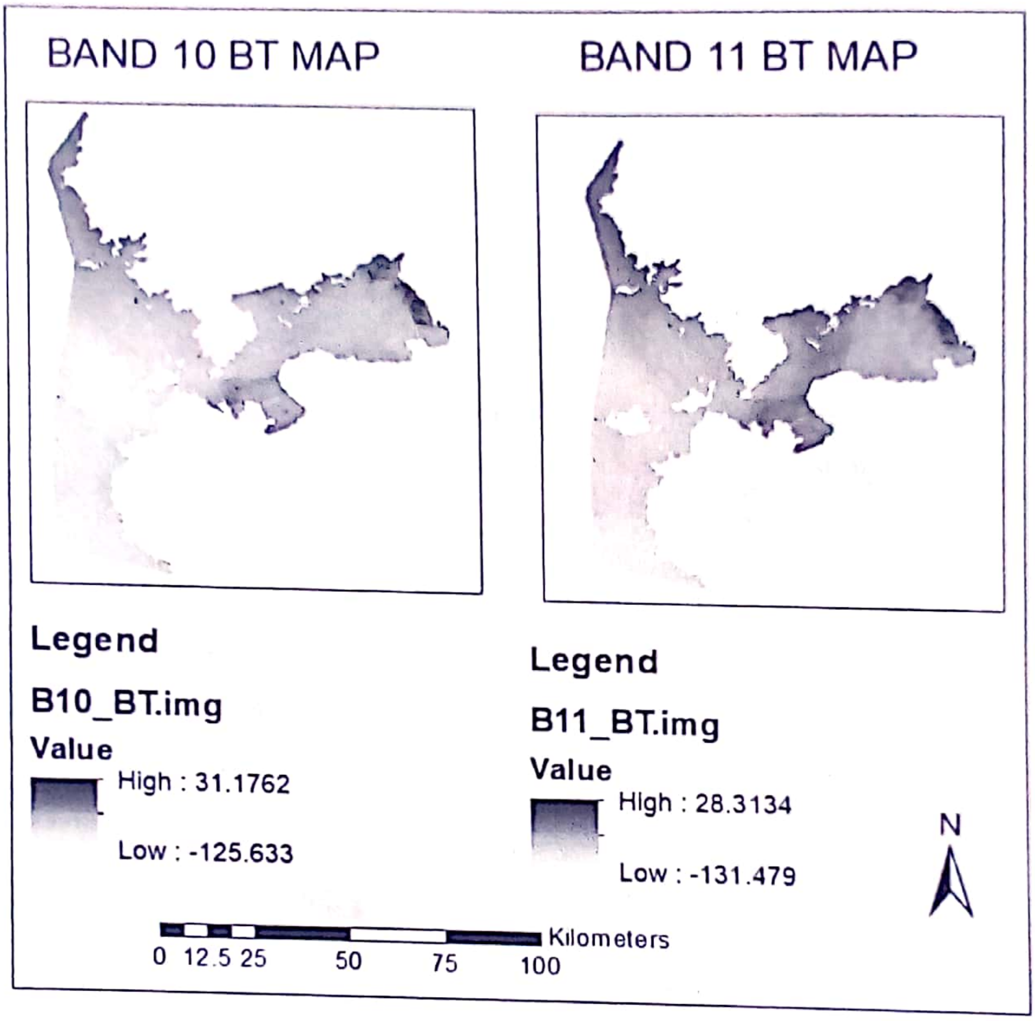


Fig.5: Brightness temperature.

Calculation of NDVI

Calculation of NDVI was important because subsequently the proportion vegetation (PV), which is highly related to NDVI and emissivity(e) which is related to PV must be calculated.

NDVI= (band 5-band 4)/(band 5+band 4)

This was computed in ArcGIS raster calculator and the NDVI image produced was as shown below;

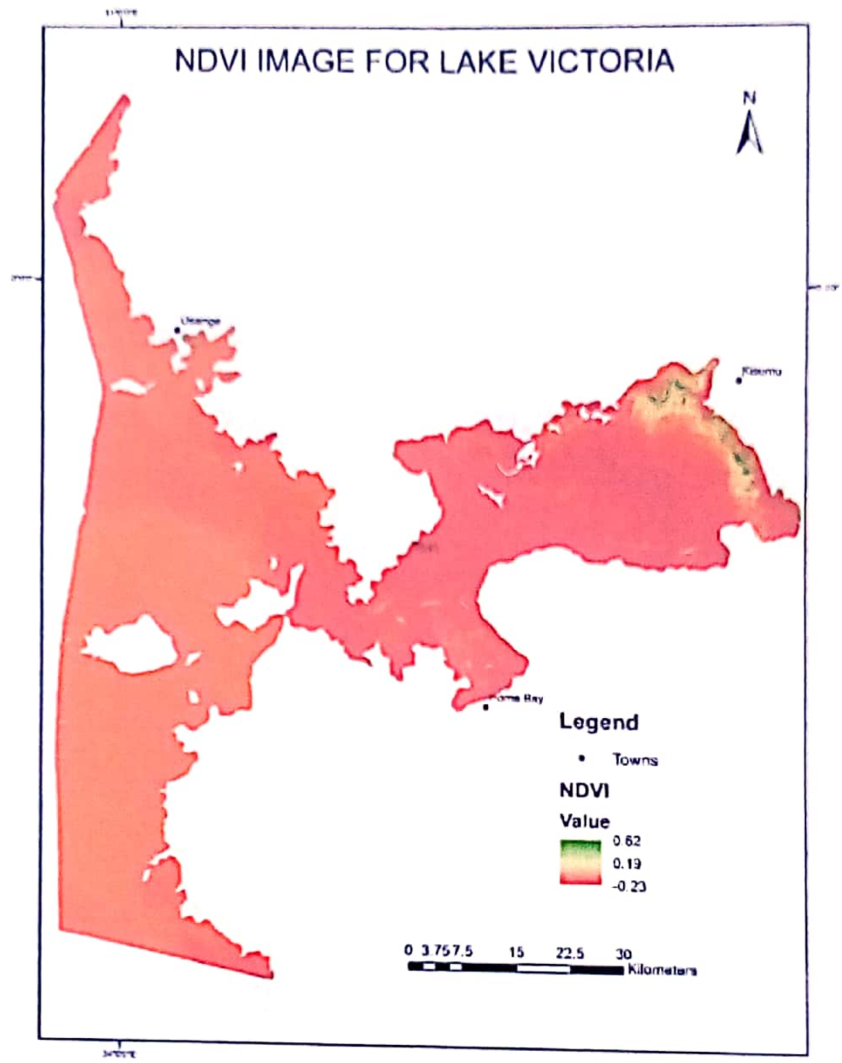


Fig.6: NDVI image.

Calculation of proportion of vegetation

Usually, the maximum and the minimum values of NDVI image are displayed directly in the image in ArcGIS, therefore PV is calculated as follows;

PV= square (NDVI-NDVI$_{min}$)/(NDVI$_{max}$-NDVI$_{min}$)

PV= square((NDVI+1)/1+1))

Calculation of emissivity

Emissivity is computed as follows

e= 0.004*PV+0.986 in the raster calculator.

The value 0.986 correspond to correction value of the equation and 0.004 is a constant.

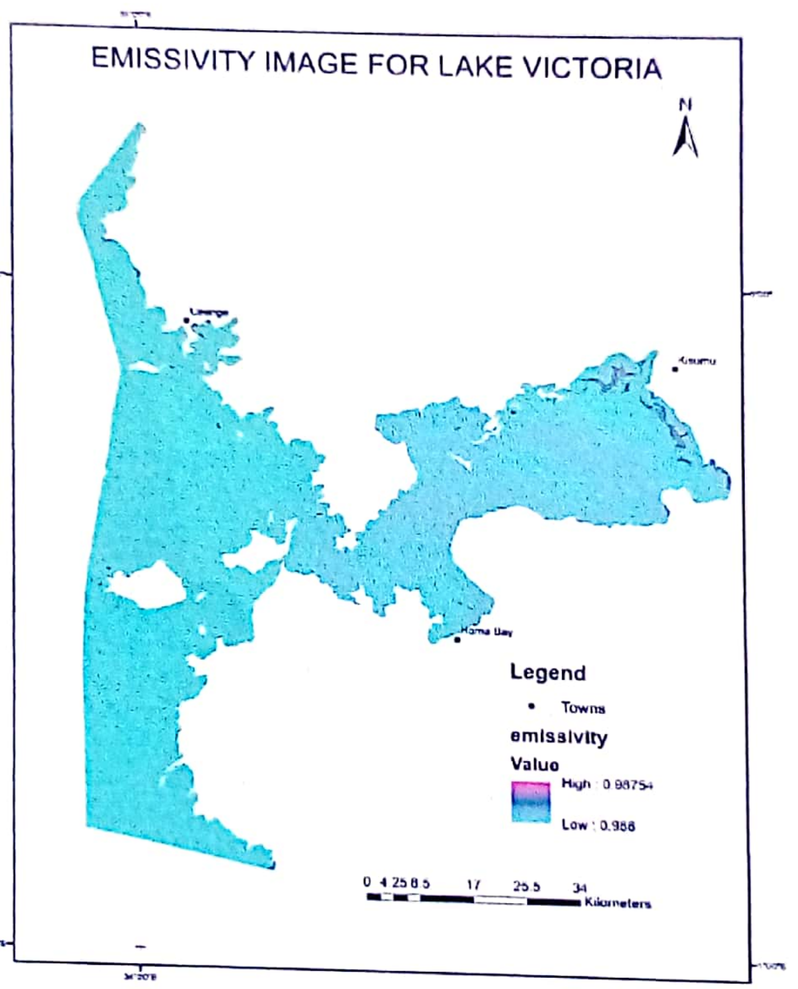


Fig. 7: Emissivity image

Calculation of lake surface temperature (LST)

Finally, the LST equation was applied to obtain the surface temperature map.

LST= BT/(1+(λ*BT/c2)*ln(e))

C2 = 14388μm

The values of **λ** for Landsat bands include;

Satellite	**Band**	**λ(μm)**
Landsat 4,5 & 7	6	11.45
Landsat 8	10	10.8
Landsat 8	11	12

The map below was extracted by mask showing only the area of interest for bands 10 and 11.

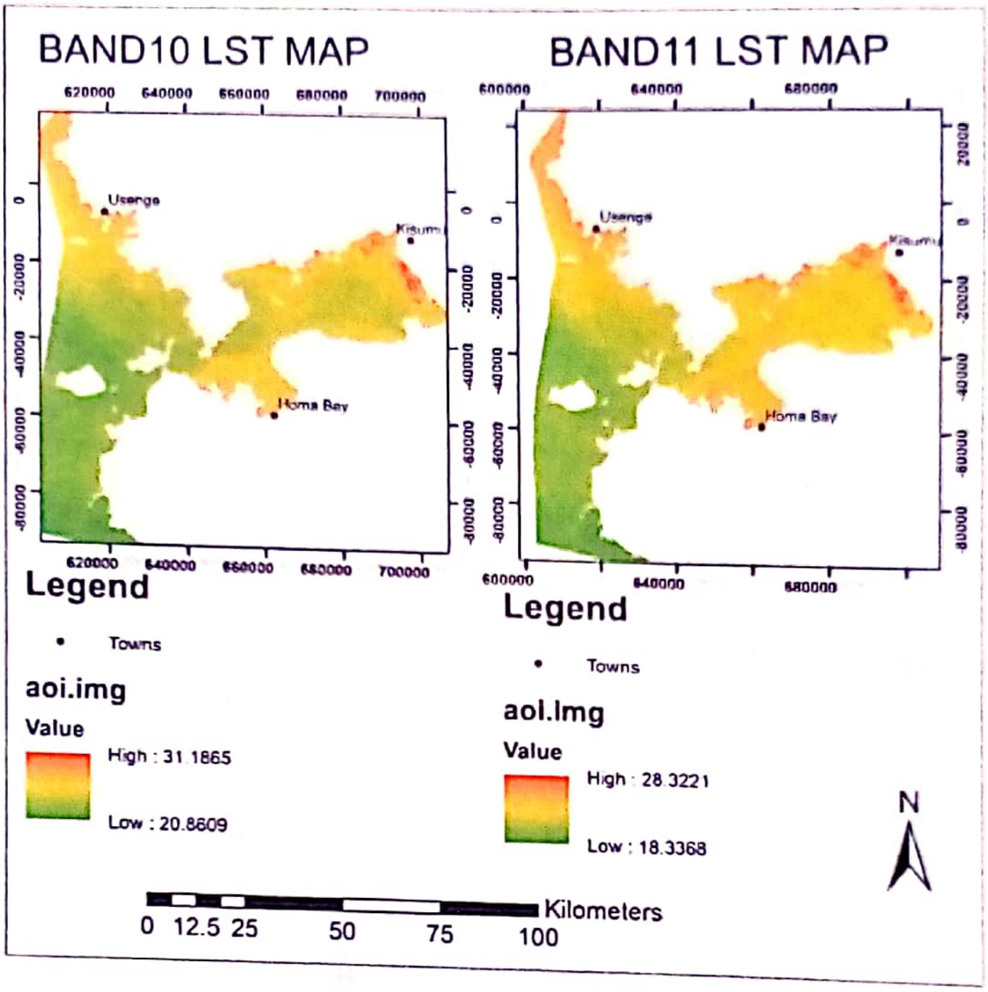


Fig.8: Lake surface temperature

1.7.2 Chlorophyll-a extraction

Since, the Landsat-8 data was stored in digital number (*DN*). It had to be radiometrically converted to the top-of-atmosphere radiance (L_{TOA}) by using following formula;

$$L_\lambda = M_\lambda x Q_{cal} + A_\lambda$$

Where:

L_λ = TOA spectral radiance

M_λ = Band specific multiplicative rescaling factor

Q_{cal} = Digital Number

L_λ = Band specific additive rescaling factor

After obtaining the radiance value, the next step was atmospheric correction that will automatically convert the top-of-atmosphere radiance value (L_{TOA}) to bottom of atmosphere reflectance using FLAASH in ENVI 5.3. FLAASH incorporates the MODTRAN radiation transfer code. It enables corrections for the adjacency effect or pixel mixing due to scattering of surface-reflected radiance.

The chlorophyll-a was extracted using band 2 and band 4 in Landsat image as follows;

Chl-a = band 4/band 2

The above processes were repeated for all the images (January, May and December 2019) the results obtained were displayed on the results section below.

1.7.3 Suitability Index Model

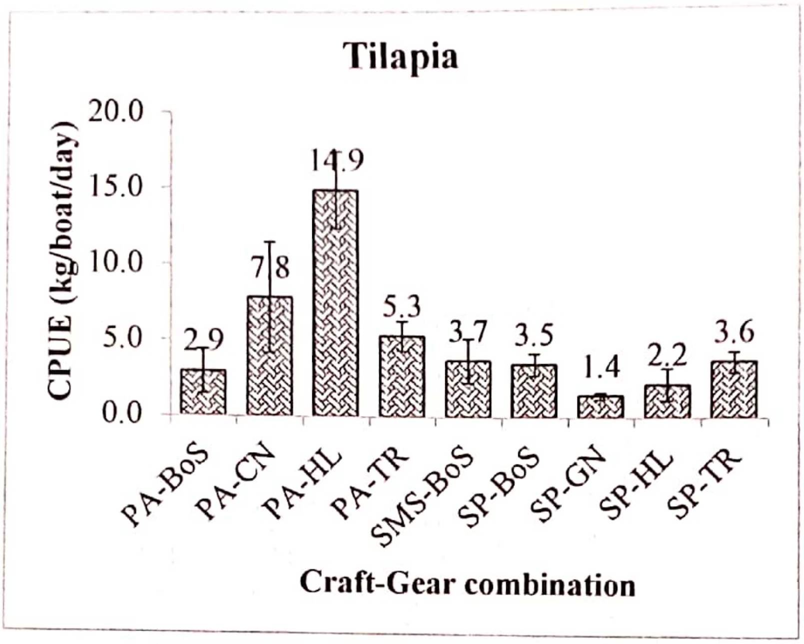
Fish catch frequency were analyzed to determine the preferred range of the fish by relating the availability of fish catch data with the satellite images.(Potensi et al., 2018). Fishing effort is often considered to be an index of fish availability or fishing occurrence (Andrade & Garcia 1999). This is to derive suitability index. Habitat suitability index (HSI) models are widely used as a tool in fisheries management, ecological impact assessments and ecological restoration studies (Maddock 1999). The HSI models usually describe relations between fish abundance and ecological variables and estimate the level of habitat suitability. *HSI* objectively assess the range of environmental condition that fully, marginally or do not meet the requirements of a species (Wakeley et al 1988). Output produced from HSI modeling can predict the spatio-temporal variation of fish habitat conditions and can be used in combination with GIS to provide maps and information upon which managers can make informed decisions in fisheries management (Terrel 1984).

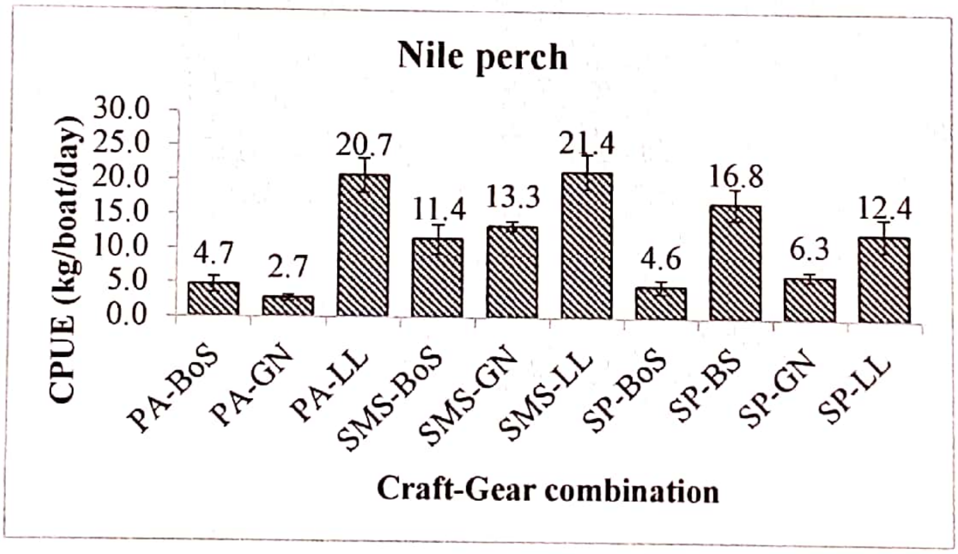
Suitability Index formula;

$$SI = \frac{Y_{fit} - \min Y_{fit}}{\max Y_{fit} - \min Y_{fit}}$$

where Y_{fit} is the predicted value of frequency (*CPUE*); and $\min Y_{fit}$ and $\max Y_{fit}$ are, respectively, the minimum and maximum frequency (*CPUE*). The suitability index determined the level of scores of the preferred ranges for fish. The satellite images were reclassified using these relevant scores to derive map of potential fishing area.

Fishery data


Tilapia
CPUE (kg/boat/day)
20.0
15.0
10.0
5.0
0.0
14.9
7.8
5.3
2.9
3.7
3.5
1.4
2.2
3.6
PA-BoS
PA-CN
PA-HL
PA-TR
SMS-BoS
SP-BoS
SP-GN
SP-HL
SP-TR
Craft-Gear combination


Nile perch
CPUE (kg/boat/day)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
4.7
2.7
20.7
11.4
13.3
21.4
4.6
16.8
6.3
12.4
PA-BoS
PA-GN
PA-LL
SMS-BoS
SMS-GN
SMS-LL
SP-BoS
SP-BS
SP-GN
SP-LL
Craft-Gear combination

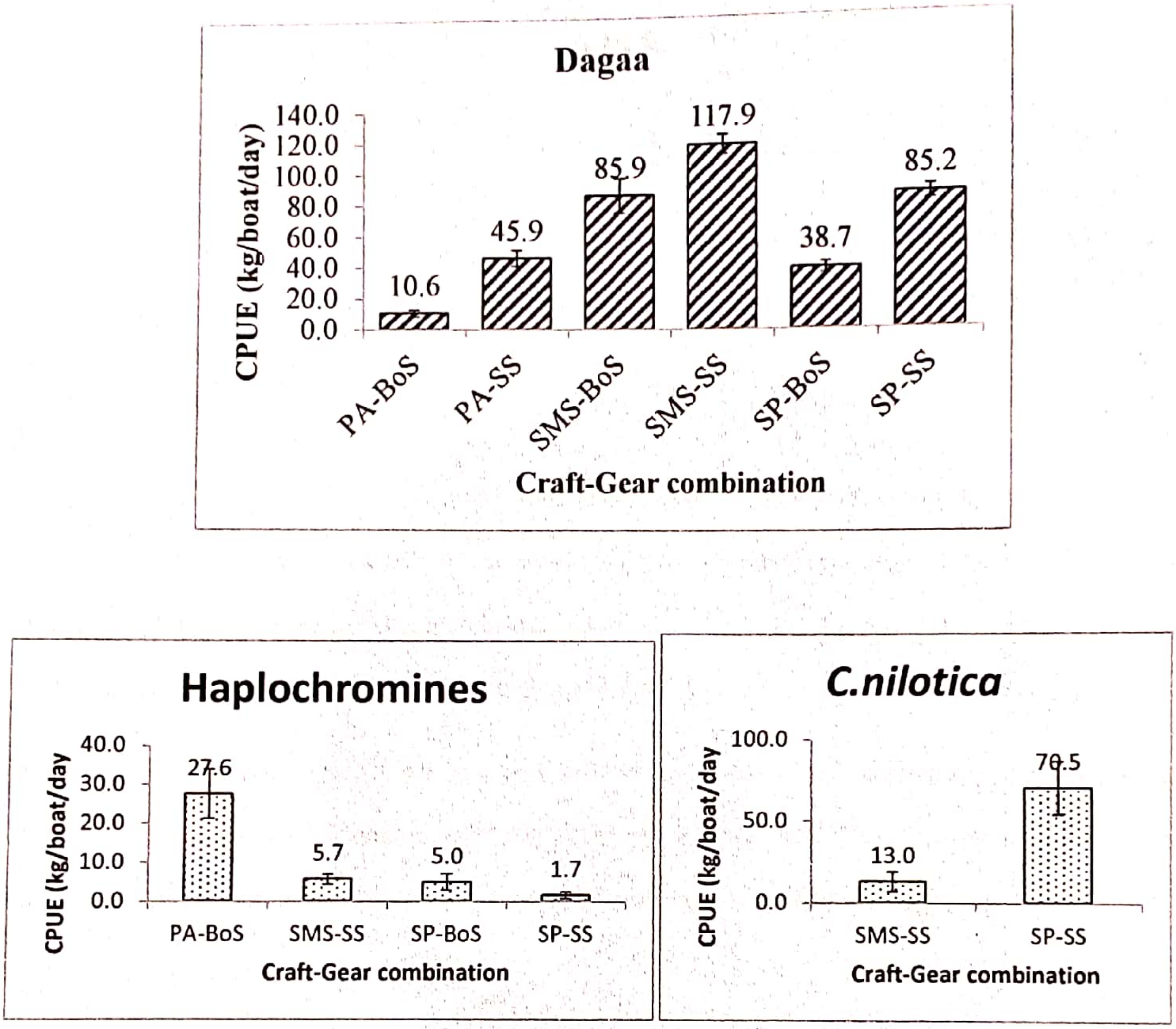


Fig.9: CPUE for different fish species.

Results

- Some of the habitat variables include;
  - ✓ Physical Habitat (substrate, depth)
  - ✓ Water quality (Water Temperature, Chlorophyll-a, Dissolved O_2, Light penetration, Nutrients)
  - ✓ Other factors (Harvest, Climate, Predation, Competition, Climate)

Lake surface temperature extraction

The lake surface temperature was obtained for the months January, May and December.

The red regions represented high temperature areas and green represents low temperature areas. For January the high temperature was observed along the lake shores of Kisumu, and parts of Siaya and Busia counties. Optimum temperature for fish breeding were along Homa bay county and some along Siaya counties.

In May high temperature were along Kisumu and Homabay while other counties the temperature were varying and cooler were in the interior of the lake. December recorded higher temperatures along Kisumu and Busia counties and lower along other counties and parts of Mbita where the temperature were optimum.

The images obtained were as shown below;

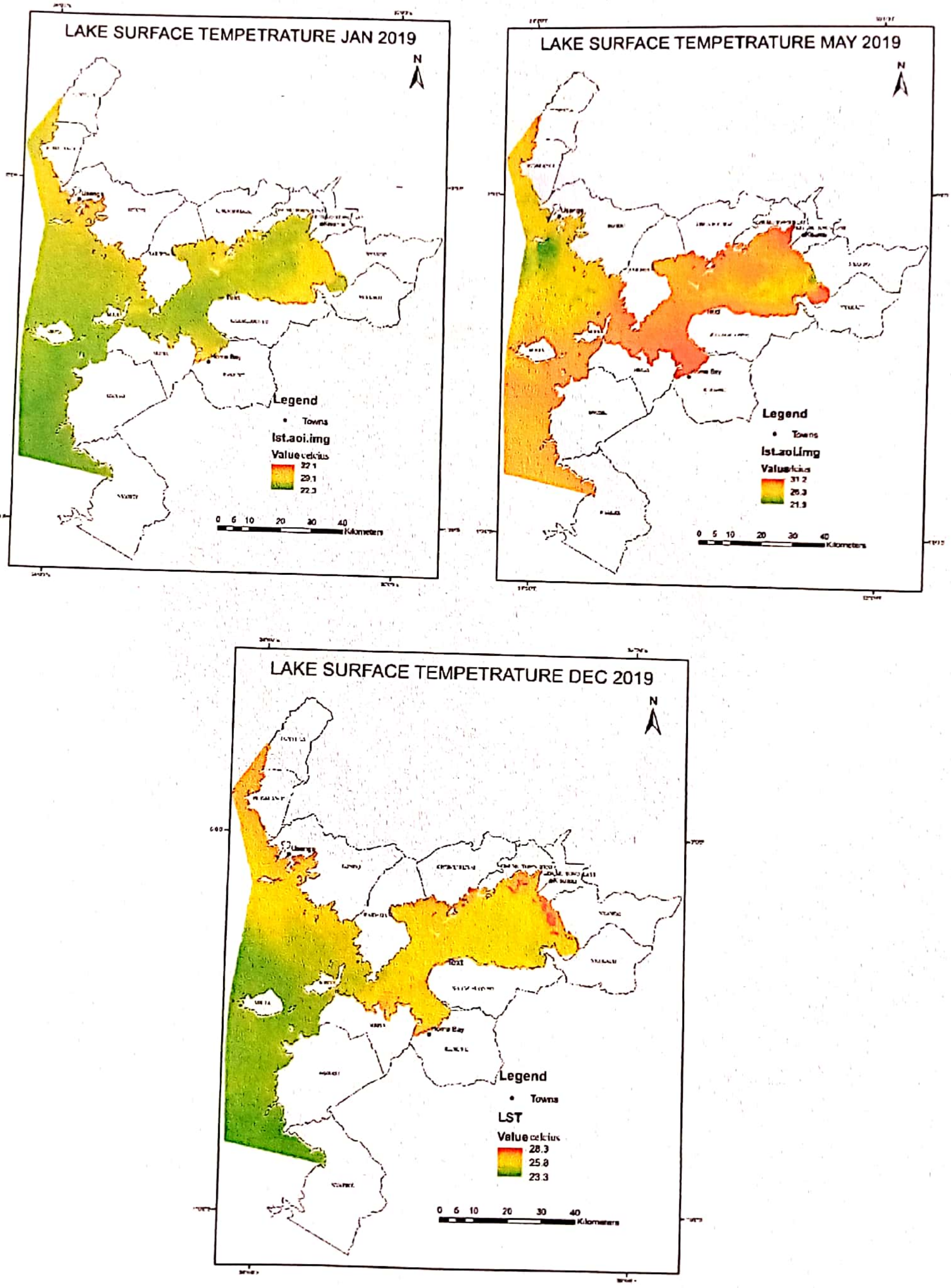
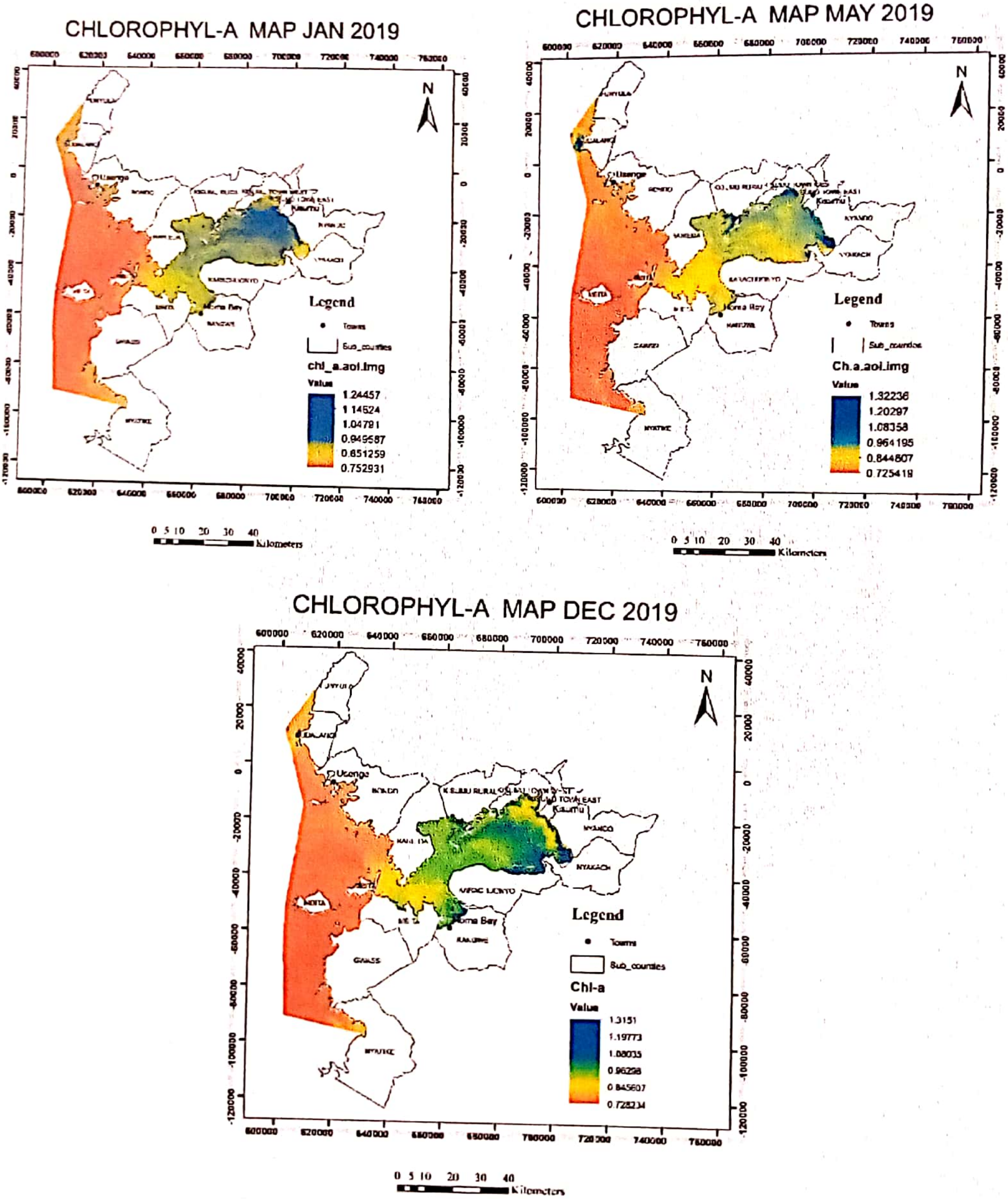


Fig. 10: Lake surface temperature for January, May and December 2019 respectively

Chlorophyll-a extraction map

- High chlorophyll-a concentration areas i.e., along shores of Kisumu, Homa bay along Rangwe, Mbita, Karachuonyo and some parts along Siaya county. This is an indication of thriving phytoplankton which fish feed on. The dark blue regions are those which show high Chlorophyll-a concentration while the reddish regions show low concentration. The optimum chlorophyll-a concentration was observed in the Homa bay and Siaya county beaches. This was constantly observed throughout the three months; January, May and December 2019.
- The chlorophyll-a maps obtained were as shown below;



g.11: Chlorophyll-a concentration maps for January, May and December 2019 respectively.

Potential fishing zones

- The potential fishing zone map shows the areas which have the most conducive variables concentration and supports fish breeding and sprawning. The blue regions are the most habitable regions which satisfy both temperature concentration and chlorophyll-a concentration. Highly habitable regions were observed around Mbita and other regions in Homa bay, Siaya, along the shores of Kisumu, Busia and Migori.
- The seasonal variation was influenced by the precipitation as well as temperature variation at different times of the year.

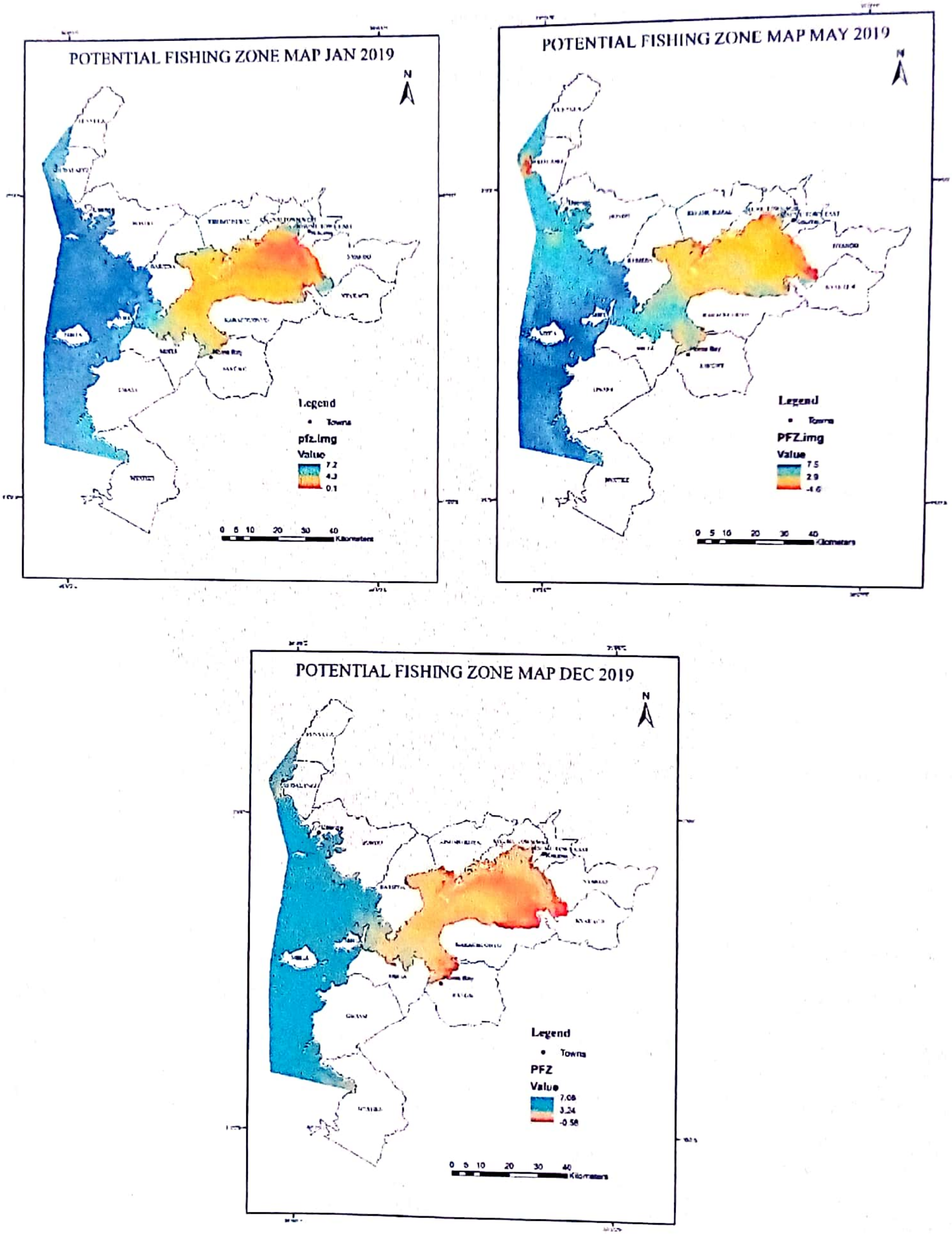


Fig.12: PFZ maps for January, May and December 2019 respectively.

Discussion

The chemical characteristics of water combined with the physical features of the stream channel influence the presence or absence of particular aquatic organisms in a stream. Habitat features affect the species distribution at different spatial scales.

Physical factors: stream meandering, steepness of banks, riparian vegetation, and variability of stream flow affect the habitat for fish in the stream.

Temperature has been long recognized to limit the range of species both in a broad geographic scale and at finer scales within particular lakes or streams. High temperatures may produce high physiological demands and stress while also reducing the oxygen saturation levels of water thus combination of increased metabolic demand and decreased oxygen availability can prove limiting or lethal. Low temperatures may also limit the distribution of species and affect community composition.

Depth of streams is negatively correlated with the probability of freezing and oxygen depletion and with high water temperatures. Shallow streams are more variable with greater extremes in the range of conditions experienced by the associated communities in much the same way that shallow lakes experience greater extremes annually.

Substrate surface irregularities, such as rocks or woody material (i.e., necro mass), alter the stream flow and deepen some regions through hydraulic scouring with fish being attracted to the area because it is energetically less demanding than maintaining a position in the open water. Depth and Water velocity are the most important requirements of spawning fish and depth is probably the most serious limitation fish passage during periods of reduced flow. Moreover, there exists minimum and maximum depth for each species.

Predation: is a major determinant of ecological local patterns in fresh water fish communities. Direct and indirect effects of predation influence a wide variety of individuals, population and community patterns, such as habitat selection, size distribution and species diversity.

Competition: most observational studies do not test directly whether competition is the most plausible mechanism responsible for the patterns observed or whether other uncontrolled factors could give rise to similar results.

Chemical variables: Of all the chemical substances in natural waters, oxygen is one of the most significant. The annual cycle of oxygen in a stream is closely correlated with temperature. The principal chemical factors affecting community composition identified repeatedly in studies of lake and stream fish communities are dissolved oxygen levels.

Climate change affects fish populations through its influence on physical environmental factors such as water chemistry and physical limnology. Fish are sensitive to many stresses from parasites or diseases to acidification.

(Gebrekiros ST (2016) Factors Affecting Stream Fish Community Composition and Habitat Suitability. J Aqua Mar Biol 4(2): 00076. DOI: 10.15406/jamb.2016.04.00076)

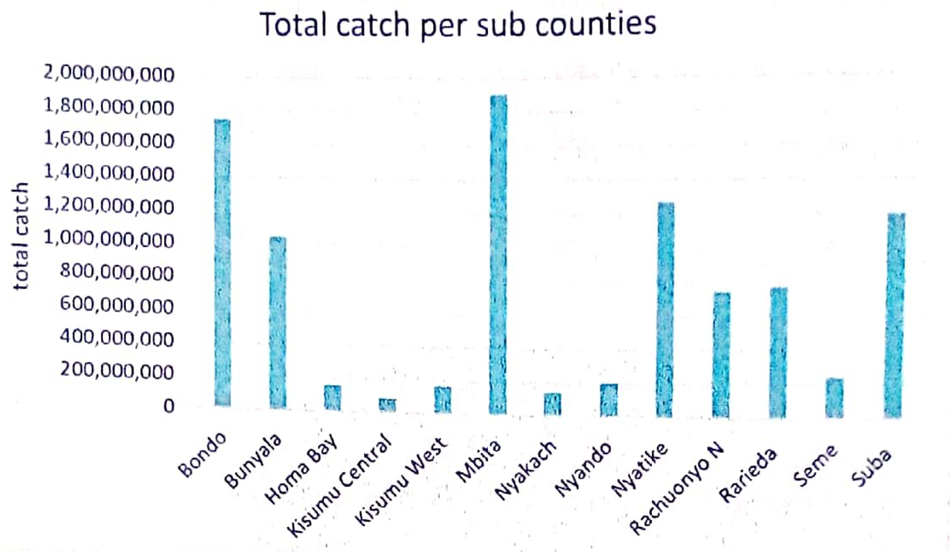
The variability of the CPUE was observed;

CPUE (Kg/boat/day

Average Catch Rate (kg/boat/day)

Craft	Gear	NP	TL	DA	HA	Carl	BD	PA	CG	SYNO	SCH	NP-J	OT	BAC	CRAFTS
PA	BOS	4.66	2.94	10.63	27.63	-	-	0.25	0.84	-	-	-	7.13	0.902	409
PA	BS														26
PA	CN	-	7.80	-	-	-	-	-	-	-	-	-	-	0.714	87
PA	GN	2.74	0.63	-	0.60	-	-	0.05	0.54	-	-	1.44	5.78	0.775	1,996
PA	HL	-	14.89	-	-	-	-	-	-	-	-	-	0.69	0.563	152
PA	LL	20.65	-	-	-	-	0.07	2.21	0.21	-	-	-	-	0.628	535
PA	SS	1.11	0.20	45.88	0.25	-	-	0.61	0.89	-	-	3.60	30.97	0.821	159
PA	TR	-	5.31	-	-	-	-	-	-	-	-	-	-	0.821	40
SMS	BOS	11.41	3.71	85.88	-	-	-	1.12	0.12	-	-	-	-	0.958	52
SMS	BS	19.75	1.25	-	-	-	-	-	-	-	-	-	-	0.964	60
SMS	CN														1
SMS	GN	13.32	0.71	-	0.06	-	0.01	0.71	1.34	0.21	-	1.85	0.65	0.756	903
SMS	HL														4
SMS	LL	21.35	-	-	-	-	0.04	0.38	0.61	-	-	-	0.05	0.641	395
SMS	SS	0.13	-	117.87	5.74	13.04	-	0.01	-	-	-	0.01	-	0.708	923
SMS	TR														6
SP	BOS	4.57	3.46	38.67	4.95	-	0.01	0.73	2.36	0.17	-	4.35	1.25	0.716	269
SP	BS	16.79	0.54	1.50	-	-	-	-	0.46	0.21	-	3.75	-	0.830	765
SP	CN														13
SP	GN	6.27	1.41	-	0.03	-	0.06	0.47	0.95	0.29	0.02	1.31	0.16	0.735	2,645
SP	HL	0.17	2.17	-	-	-	-	-	-	-	-	-	0.33	0.810	86
SP	LL	12.44	-	-	-	-	-	1.67	1.72	-	-	-	-	0.651	2,294
SP	SS	0.11	0.02	85.20	1.66	70.54	-	0.01	0.02	-	-	-	-	0.676	1,481
SP	TR	-	3.63	-	-	-	-	-	-	-	-	-	-	0.821	31
		9.34	**0.78**	**30.83**	**1.74**	**9.95**	**0.02**	**0.43**	**0.75**	**0.09**	**0.00**	**1.10**	**1.59**		**13,352**

The high CPUE indicate the abundance of fish species and therefore encourages harvesting, low CPUE signifies depletion or overexploitation of the fish species, therefore actions should be taken to stop harvesting. Unchanging CPUE indicates sustainable harvesting.



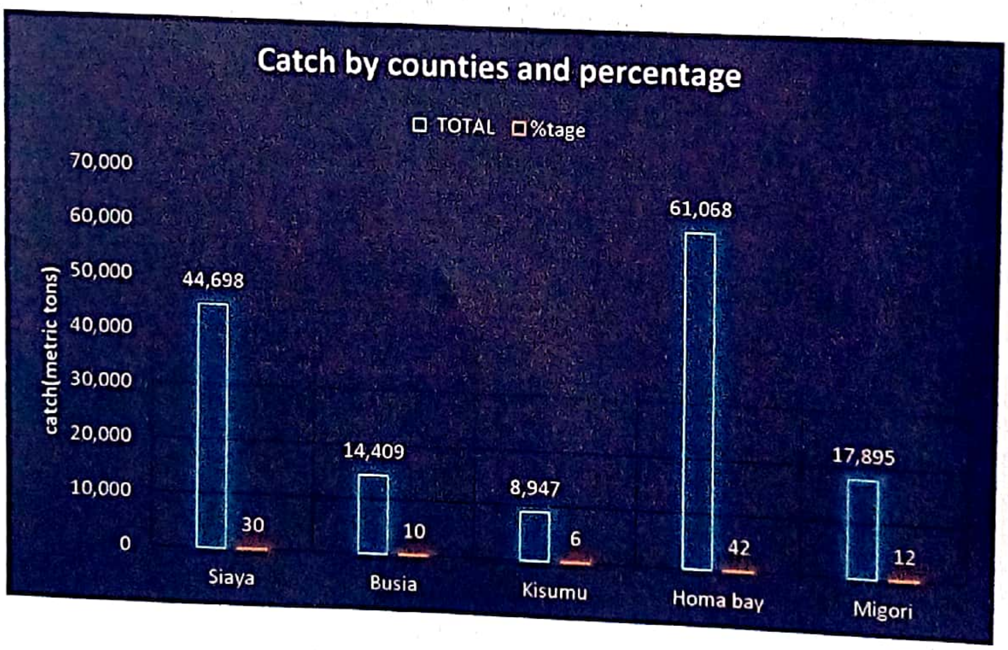


Fig.13: total catch per sub-counties and counties.

The measurement of the chlorophyll is used as an indicator of ecological productivity. Results showed variations of chlorophyll-a in the study area to a range between 0.7-1.3.

High chlorophyll-a values recorded in the area indicate a high phytoplankton biomass therefore high nutrient, organic matter and phytoplankton biomass create a good environment for fish larvae.

Variable	Range	Optimum Range	Percentage of catch in areas with optimum range
LST	20-31	23-27	94
Chl-a	0.72-1.31	0.8-1.0	90

Analysis of Suitability Index

The actual fish catch was plotted on the map to indicate the actual fish catch value in the potential fishing zones. High potential fishing zones were obtained along the shores also the Homa bay county regions, parts of Siaya, Kisumu and Migori counties. Suitability Index analysis of preferred ranges for lake surface temperature and chlorophyll-a were as shown below.

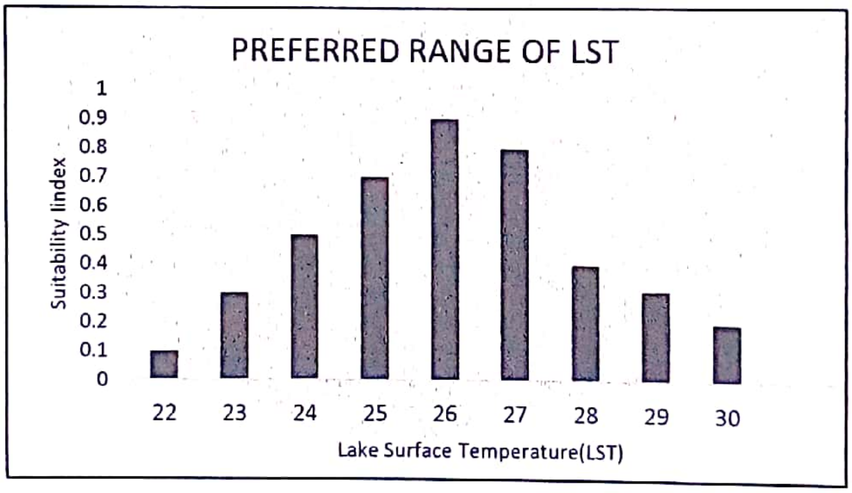


Fig.14: suitability index analysis indicating preferred range of LST.

The suitability index was higher at optimum temperature an indication the most catch was obtained at optimum temperature regions i.e., from 24°C to 27°C. High suitability index satisfies the optimum temperature which favours thriving of fish habitat variables thus abundance of fish.

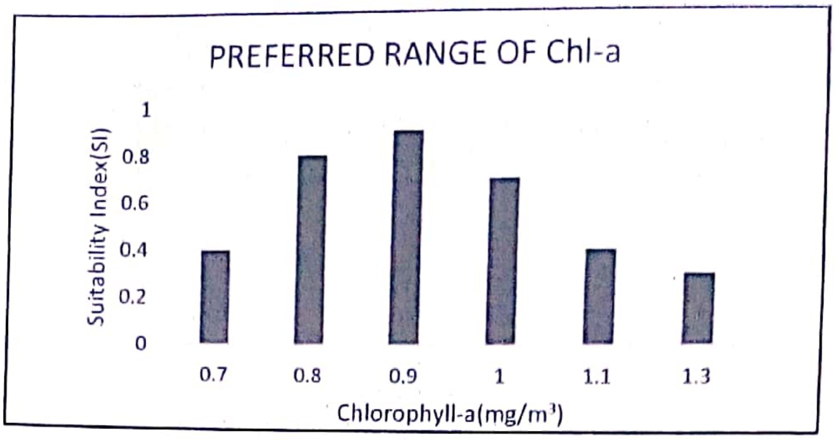


Fig.15: suitability index analysis indicating preferred range of Chl-a.

The suitability index was higher at the optimum chlorophyll concentration (0.8 to 1.1mg/m^3) which favours the development of phytoplankton which fish feed on.

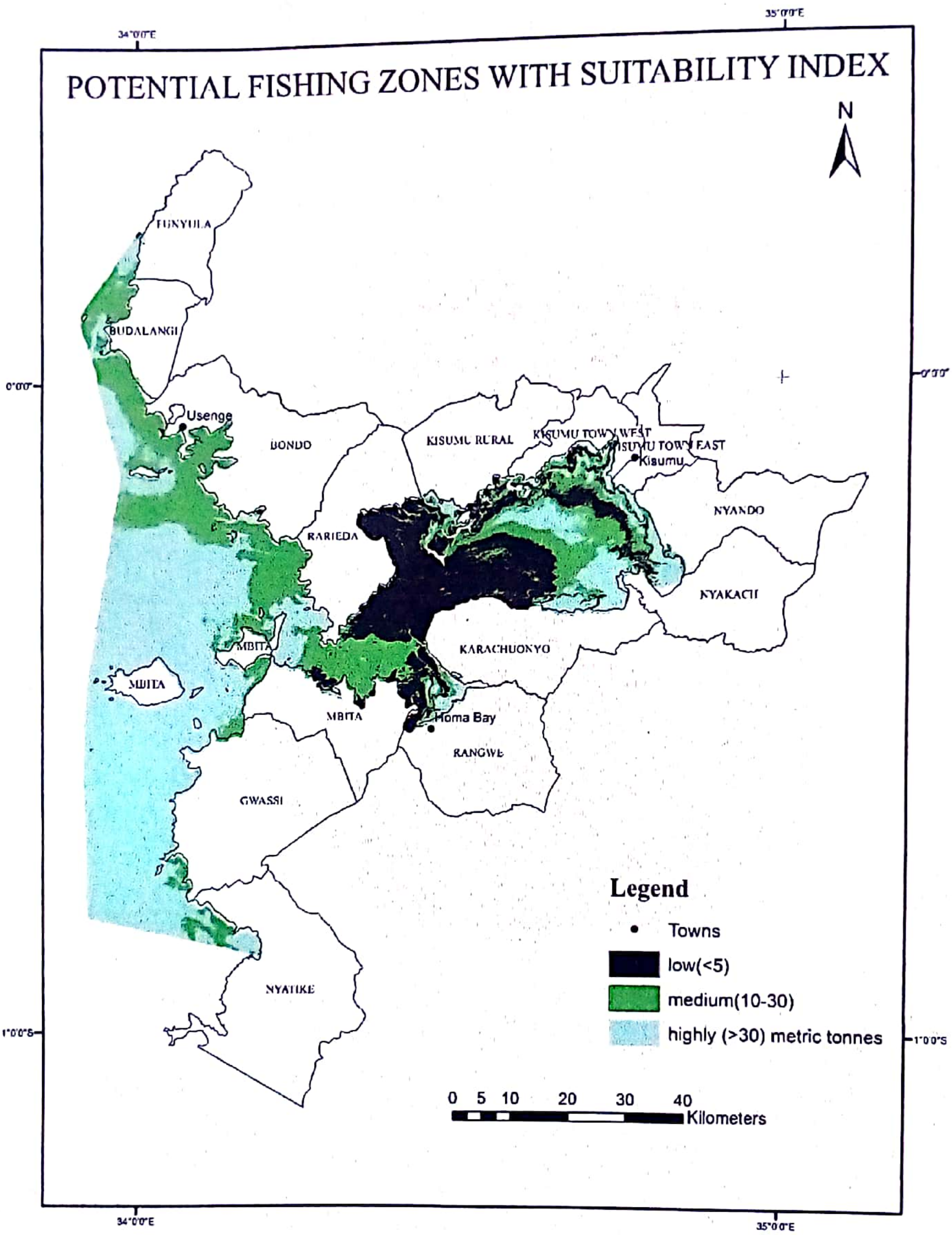


Fig.16: PFZ map using suitability index.

Seasonal distribution of the habitat

From this study the distribution of the essential fish habitat was observed along beaches of Homa bay, Mbita region, this is due to abundance of chlorophyll-a in these regions as observed above.

From figure 16 above the distribution is represented in terms of the suitability index obtained from the CPUE. The low habitable regions are regions which registered catch of less than 10 metric tonnes, and were observed around Kisumu county. Highly habitable regions were observed along the Mbita in Homa bay county and some in Siaya county, they registered catch greater than 30 metric tonnes. Other regions recorded between 10 and 30 metric tonnes.

From this study therefore highly habitable areas were along the Homa bay and Siaya county beaches.

Conclusion and outlook

In this study the data used were catch data and satellite derived environmental variables to determine habitat suitability indices for fish. We found that more than 90% of the total catch came from the areas with sea surface temperature 23.0°–28.3°C and chlorophyll-*a* concentration 0.72–1.31 mg/m^3. This study demonstrated that potential fishing zones of fish can be mapped using suitability index model, with fish catch data and satellite imagery components. The satellite data is advantageous since they categorize the aquatic properties of habitat and ecosystems the influence living aquatic resources at spatial and temporal resolutions. Based on the datasets available, there is a variation in the level of nutrients, chlorophyll-a and lake surface temperature in Lake Victoria. The lake can be classified as a shallow nutrients-rich productive area between shore and offshore and are important in sustaining the fishery.

The study can therefore be concluded that the most essential fish habitat regions in the Lake Victoria were along Homa bay and Siaya regions as observed from figures, 12 and 16. Fish habitat is dynamic and changes due to environmental, climatic factors and also human activities affecting the lake and its surrounding. The PFZ maps varied for the months indicating that the habitat is not constant since the factors vary with precipitation for instance affects the chlorophyll concentration for phytoplankton thriving. Therefore, Habitat Suitability Index is an essential tool for mapping essential fish habitat in aquatic environment.

Recommendations

- Encourage collaboration and increased integration of methodological approaches used by taxonomists and other scientists to increase accuracy, repeatability and the creation of enhanced tools.
- Need for continous monitoring of fish breeding sites in order to understand the temporal trophic dynamics of the ecosystems and to come up with the better and informed management strategies.
- Increase awareness among the public and policy-makers of the importance of accurate fish identification through the use of user-friendly media and advocacy.
- Need to develop more local, scientifically reviewed and curated reference collections of fish specimens (in fishery agencies, institutes) and encourage their use and approved data acquisition techniques.
- Development of fishery database with all datasets for various applications and to quicken the fishery data access remotely.

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1 Introduction

1.1 Background

Lake Victoria supports the largest inland freshwater fishery on earth. The lake traverses the three East African Countries: Kenya, Uganda and Tanzania. It has a surface area of 68,500km^2 shared between Kenya (6%), Uganda (43%) and Tanzania (51%). The Kenyan portion of the lake covers an area of 4128 km^2. This portion produces the bulk (80%) of the country's annual fish landings. The lake had high fish species diversity of over 500 species of fish most of which were endemic but following the introduction of Nile perch and tilapiine cichlids, coupled with over exploitation and environmental degradation, many native species have since disappeared from the lake (El-Sayed, 2016). The main commercial species caught are *Rastreonobola agentea* (Omena/dagaa/mukene) 53.32%, *Lates Niloticus* (Nile Perch) 33.4% and *Oreochromis niloticus* (Tilapia) 4.31%. Fish stocks have dwindled due to heavy eutrophication, proliferation of invasive species, over-fishing and use of illegal/undersize gears.

Ecological processes at various temporal and spatial scales have created a vast array of distribution patterns. Describing the relationships between organisms and their environment is central to the understanding of these processes and the functioning of ecosystems. Consequently, studies on biodiversity and the dynamics of species distributions has a long tradition in ecology (e.g., Grinnel 1917). The configuration of habitats and the distribution of species along environmental gradients have for a long time also been affected by human interests and development. For example, in 1877, applied ecology sought the answer to an unexpected low production of an oyster bank in response to fisheries management needs (cited from Olenin and Ducrotoy 2006). Today, as habitat loss poses a major threat to ecosystems (Airoldi and Beck 2007), the need to map species and habitat distributions for nature conservation has increased dramatically (Thrush and Dayton 2010). Ecologists' interests in understanding population distribution and dynamics, combined with advancements in computer technology, have led to the development of species distribution modelling. This field of spatial modelling relates the occurrence or abundance of species to environmental descriptors and can help resolve, or raise, ecological and evolutionary questions into the underlying processes and