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Research article

Spatial coverage of water hyacinth (*Eichhornia crassipes (Mart.) Solms*) on Lake Tana and associated water loss

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ABSTRACT

The introduction of water hyacinth poses a serious threat to economic viability of Lake Tana and its environments. This study aimed to capture the spatial coverage of water hyacinth and its effect on water loss in Lake Tana using quantitative research methods. Four satellite images representing each season of 2019 were downloaded from USGS. In addition, pan evaporation data were taken from the National Meteorological Agency. ArcGis 10.4, Envi 5.3, Qgis 3.12.1 plug in CSP and Excel used to manage land use land cover classification and water loss estimation analysis. The seasonal coverage of water hyacinth was 15.35, 4.14, 11.82 and 13.59 km^2 in winter, autumn, summer and spring 2019 respectively representing 0.63 and 0.17 percent of the Lake as a maximum and minimum coverage. The mean daily evaporation of Lake Tana was 5.14 mm/day, but this increased to 18.85 mm/day due to the presence of water hyacinth. The mean net daily water loss due to water hyacinth at Lake Tana was 0.14 km^2 while 52,62 km^3 in 2019. The study concludes that water hyacinth caused enormous negative impact on the water volume reduction in Lake Tana. Management of the Lake Tana environment and control of the water hyacinth weed are recommended to sustain the Lake.

1. Introduction

Water hyacinth, *Eichhornia crassipes (Mart.) Solms*, posed a severe threat to water bodies worldwide (Labrada et al., 1995). The exertion of water hyacinth control in developing countries is a difficult mission (Labrada, 1996). Monitoring of water hyacinth pattern and extent is critical ahead of management measures (Thamaga and Dube, 2018). To successfully manage the problem of water hyacinth the role of reliable information on affected areas, extent and rate of the weed's proliferation is unquestionable (Cheruiyot, 2012). Even though the information is critically important to organize, perform and evaluate water hyacinth control projects by decision-makers, policymakers, scholars and community (Navarro and Phiri, 2000). One major challenge in the fight against the weed is data management and analysis (Kibret and Worqlul, 2018).

Remote sensing has been used to analyze the spatial coverage of water hyacinth in different parts of the world. Albright et al. (2004), Cheruiyot (2012), Mund et al. (2014) and Thamaga and Dube (2018) are the well-known works in this regard. On the other side Ayalew (2014), Tewabe et al. (2017), Asmare et al. (2020) and Dersseh et al. (2020) contributed towards the spatial coverage of water hyacinth in Lake Tana, Ethiopia. But, they did not reflect the variability of water hyacinth coverage over seasons. The seasonal variation of the weed across the year has valuable implications in the management of the weed. Hence, there is a gap in the thematic development of water hyacinth studies in Lake Tana.

Water hyacinth invasion creates a number of problems to the water bodies and the community settled around (Mailu, 2001; Ezama, 2019; Honlah et al., 2019). This invasive water hyacinth weed is quite dangerous for the livelihoods of the people (Ebro et al., 2017). It affects the fishery, crop and livestock production of the people (Tewabe, 2015). On the other hand, the weed disrupts the quality and quantity of water, flora and fauna resources of water bodies under infestation (Mailu, 2001). One of the environmental problems posed by the weed is water loss (Sasaqi et al., 2019). The thick mats of the weed increases evapotranspiration (Saleh, 2016). The lake hydrology will be meaningfully impacted through the growing evapotranspiration caused by the weed mat (Dersseh et al., 2019). Several scholars have confirmed that the evapotranspiration process of water hyacinth elevates the water loss as compared to evaporation from a free water body (Van der Weert and

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Kamerling, 1974; Herfjord et al., 1994; Cock, 2004; Rashed, 2014). The high amount of water loss in the process will decrease the volume of water designed for developmental works which will in turn hamper the water-dependent industries and livelihoods including irrigation-based agriculture (Arp et al., 2017).

Efforts to analyze the impact of the weed on water volume loss due to evapotranspiration is suppressed (Arp et al., 2017). Nevertheless, there is a need to determine the amount of water used by different water hyacinth species over time, this information will help to prioritize their removal and control strategies (Thamaga and Dube, 2018). Eventually almost nothing has been done on the volume of water wasted due to water hyacinth on the Lake Tana while the weed is responsible for the problem through the process of evapotranspiration. Dersseh et al. (2020) have pointed out that the evapotranspiration of Lake Tana is historically undiscovered and it is vital to reveal the amount of water lost. Therefore, the objective of this study was to analyze the spatial coverage of water hyacinth and its effect on water volume in Lake Tana. Since the weed is available only on the northeastern part of Lake Tana, the study is limited to part of the lake. Output of the study generated first-hand information on the water loss problem of water hyacinth and provided an insight towards the usage of remote sensing for water hyacinth detection and water loss estimation.

2. Materials and methods

2.1. Study area description

Lake Tana is the largest of the 15 Lakes in Ethiopia (WB, 2006) covering more than 3000 km (WB, 2006; Vijverberg et al., 2009; Goshu and Aynalem, 2017). The lake is shallow lake with average depth of 8 m (Vijverberg et al., 2009; Tewabe, 2015) up to 9 m (Mundt, 2011; Ejigu and Ayele, 2018) and a maximum depth of 14 m (Vijverberg et al., 2009; Ejigu and Ayele, 2018). As the largest lake in Ethiopia and the third largest in the Nile Basin, half of Ethiopia's freshwater is locked up in Lake Tana (Vijverberg et al., 2009; Mundt, 2011). The lake is the one in which the worst amount of water hyacinth infestation exists in Ethiopia (Admas et al., 2017). The weed is concentrated only on the northwestern side of Lake Tana. Therefore, the study simply focused on the northeastern part of Lake Tana with one km buffering (see Figure 1).

2.2. Data collection

The study was based on explanatory research design and satellite images and meteorological data. Four Sentinel-2 satellite images were downloaded to coincide with the middle of the month of Ethiopian definite climatic seasons during 2019. In Ethiopia there are four climatic seasons (Fazzini et al., 2015). The seasons have distinct months: Winter/*Bega* (December, January and February), autumn/*Belg* season (March, April, May), Summer/*Kiremt* season (June, July, August), and Spring/*Tseday* (September, October and November) (Westphal et al., 1975; Glantz, 2002; Wolde-Georgis, 2002). Seasons have relative climatic similarity across days of the seasons. The climatic conditions similarity across the seasons contributes for variation on water hyacinth coverage in connection to other factors like water hyacinth management (Dersseh et al., 2019).

The study used satellite images downloaded at the middle months of the seasons as a representative of the 2019 for the water loss estimation. This is because the monthly analysis of water hyacinth was not possible in some months of summer due to high cloud cover while the annual variation can be captured by the seasonal data analysis. Therefore four Sentinel 2 images, one per season, were acquired on sunny days. Satellite images with cloud levels of less than 10 percent were accepted for the analysis of study. Raw satellite images can have errors and cannot be directly utilized for features identification and any applications. Preprocessing is a prerequisite ahead of extracting information from satellite (remote sensing) images about the surface of the earth (Ceamanos and Valero, 2016). Therefore, preprocessing of satellite images was conducted before the analysis. The details of images properties are summarized in Table 1.

In addition, the evaporation data was collected from the National Meteorology Agency West Amhara Meteorological Service Center, which is based in Bahir Dar city. The pan evaporation data collected by the center was adopted as Lake Tana free water evaporation. Since the center was very close to the lake and found within a similar altitude the climatic

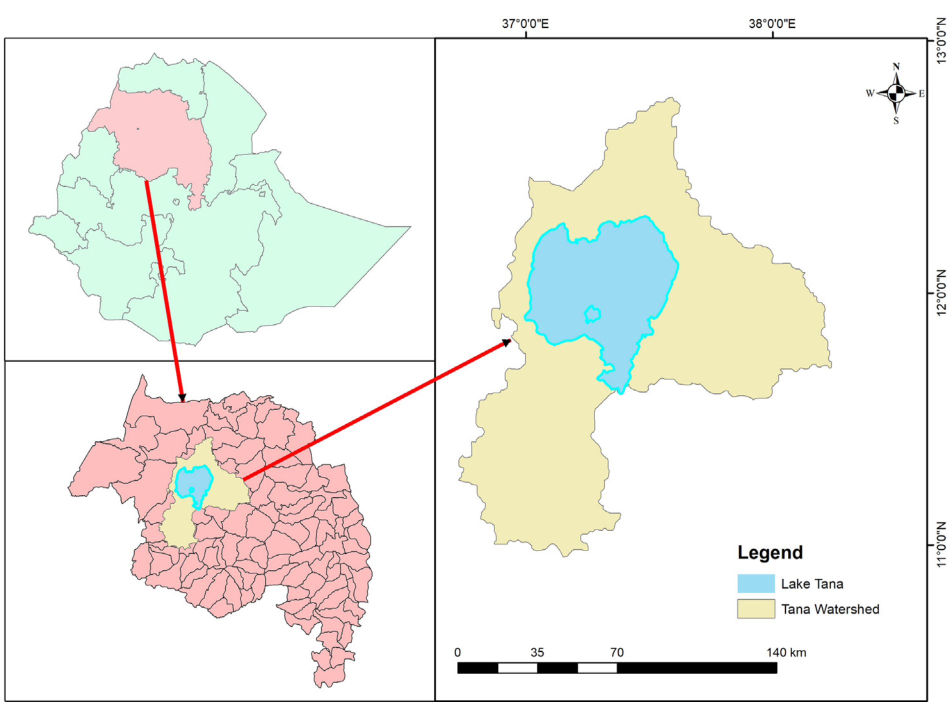

Figure 1. Location map of Lake Tana. Source: Authors production using Ethio-Gis spatial data, 2020.

Table 1. Characteristics of spatial data used for analysis.

Year	Data Type	Sensor	Date of acquisition	Resolution	Source	Remark
2019	Sentinel 2	MSI	2019/10/29	10 m × 10 m	USGS	Spring
2019	Sentinel 2	MSI	2019/01/12	10 m × 10 m	USGS	Winter
2019	Sentinel 2	MSI	2019/04/17	10 m × 10 m	USGS	Autumn
2019	Sentinel 2	MSI	2019/08/30	10 m × 10 m	USGS	Summer

condition was similar. Thus, it was assumed that the center data could represent the conditions of the Lake. Missed data in the daily pan evaporation data was filled by taking the monthly average data.

2.3. Data analysis

Based on the nature of the data the analysis techniques were selected. The analysis techniques were descriptive statistics, maximum likelihood classification and water loss estimation. Analysis of the study was managed by ArcGis 10.4, Envi 5.3, Qgis 3.12.1 plug in CSP and Excel. Results of the data analysis were presented in thematic maps, graphs and tables.

2.3.1. Maximum likelihood classification (MLC)

To perform the classification the maximum likelihood supervised classification (MLC) was employed. Maximum likelihood classification is a supervised classification that categorizes the satellite images of the study area into various land use land cover classes based on the prior experience of the area. This classifier was purposively selected due to its wider application and better reliability (Richards, 1995). To perform the classification analysis three major steps were followed: training areas were identified first, then endmembers/signatures developed and finally classification of satellite images performed. Endmembers were developed for all spectral classes composing each information class to be identified by the classifier. Since there could be more than one spectrally different signature for each land cover class each of the classes are represented by several spectral classes. Based on the recommendation of the Eastman (2001) and Akgün et al. (2004), the number of endmember pixels were sated as 10 times more than the land use land cover classes. A recode function was used to merge spectrally different classes to generate final information classes.

Four Sentinel 2 images related to the study area were processed. Each image was targeted to represent the season and they were selected at the middle of the season. The maximum likelihood supervised classification was performed to the six land use land cover classes: water hyacinth, water, forest, bare land, agricultural land and other vegetation. Then the classified images were reclassified into three classes of water hyacinth, water and others for better visualization of the weed.

2.3.2. Water loss estimation

Besides the impact of water hyacinth on the quality of water, it also causes water loss through evapotranspiration. Studies conducted by Yirefu et al. (2007) revealed the water quantity impacts of water hyacinth. Water hyacinth creates more water loss through generating more evapotranspiration. Due to the evapotranspiration process of the weed, more water is consumed which is the reason for the reduction of water bodies covered by the weed. Evapotranspiration is the loss of water by both evaporation from soil or water surface and by transpiration from plants. Transpiration is the modified form of evaporation and it is evaporation of moisture from plants. The rate of transpiration is high when the water bodies covered by plants like water hyacinth (Timmer and Weldon, 1967). Thus, it is noteworthy to quantify the importance of water hyacinth on water loss.

The study estimated the water loss due to the weed in recognition of the procedures forwarded by Arp et al. (2017) and Rashed (2014). Data on spatial coverage of the weed, evaporation from the free Lake Tana, water hyacinth evapotranspiration (ET_{WH}) and plant coefficient of water hyacinth (Kc) were needed to estimate water hyacinth caused water loss in Lake Tana. The estimation of water loss in Lake Tana was with the assumption all weed laid on water and it proliferates with expense of the Lake water.

Scholars have found different plant coefficient of water hyacinth (Kc) which was the ratio of water hyacinth evapotranspiration to evaporation from free water. The plant coefficient of water hyacinth driven through the following formula (Rashed, 2014)

$$Kc = ET_{WH}/Ev \tag{1}$$

Where Kc- represent plant coefficient of water hyacinth, ET_{WH} – evapotranspiration of water hyacinth and Ev – evaporation from free water surface.

Literature review conducted by Arp et al. (2017) depicted Kc values of the water hyacinth range from 1.02 to 9.8. However, the plant coefficient of water hyacinth (Kc) for the sake of this study was generated by using the data of Timmer and Weldon (1967). The study conducted by Timmer and Weldon (1967) showed that the weekly average evapotranspiration rate of water hyacinth is 3.96 inches while the free open water is 1.08 inches per week. The ratio of water hyacinth evapotranspiration (ET_{WH}) to open water bodies evaporation (Ev) is 3.667 (Timmer and Weldon, 1967). The data was selected purposively among others on the issue due to its applicability in tropics and subtropics including Lake Tana. In addition, authors frequently used it for similar purposes, water loss estimation caused by water hyacinth.

The evaporation can be generated from different mechanisms including Food and Agriculture Organization (FAO) Penman–Monteith equation, meteorological data and pan evaporation data among others. For this study, meteorological pan evaporation data was used to generate the evaporation from the free water surface of Lake Tana. Daily pan evaporation data from National Meteorology Agency based in Bahir Dar around Lake Tana was used to capture evaporation from free water (Ev) representing evaporation of Lake Tana.

Then the water hyacinth evapotranspiration (ET_{WH}) calculated using the evaporation from free water surface (Ev) and plant coefficient of water hyacinth (Kc).

$$ET_{WH} = Ev^{*}Kc \tag{2}$$

The volume of net daily water loss (NDWL) generated by water hyacinth was estimated by the following formula which was modified from Rashed (2014).

$$NDWL = ((ET_{WH} - Ev) * \text{Area of Water Hyacinth})^{*}\ 10^{-9} \tag{3}$$

Where net daily water loss (NDWL) due to water hyacinth was in km^3, area of water hyacinth in km^2, ET_{WH} and Ev was in mm day–1.

The amount of water lost within a season was estimated by multiplication of net daily water loss (km^3) and number of days in the season.

2.3.3. Accuracy assessment

The accuracy of maximum likelihood based land use land cover classifications was checked using ground truth region of interest (ROIs). Overall classification accuracy, producer accuracy, user accuracy and Kappa coefficient were computed to assess the accuracy of the classification. Confusion matrix is a common tool of measuring the correct and incorrect classifications made by the classifications employed (Kulkarni et al., 2020). Producer's accuracy is a measure of omission error and calculated as the total numbers of correct pixels in a category divided by the total numbers of pixels of that category as derived from the reference data. On the other side, user accuracy is a commission error (errors of inclusion) which is calculated as the total number of correct pixels in a category divided by the total number of pixels that will be classified in that category (Congalton, 1991; Lunetta et al., 1991). The lowest acceptable classification level is stated as 85% and above (Anderson, 1971; Foody, 2008).

The other classification measure is Kappa coefficient (K value) which reveals the extent of errors generated from simple random classification. The Kappa coefficient has a score of 0–1. Landis and Koch (1977) has given a benchmark of less than 0.00 Poor, 0.00–0.20 slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial and 0.81–1.00 almost perfect.

3. Results and discussion

3.1. Spatial coverage of water hyacinth on Lake Tana

The proliferation of water hyacinth increased over time that had negative consequences on the normal pattern of land use land cover over Lake Tana and surrounding areas. Water hyacinth was first observed at Megech in 2011 at the northeastern tip of Lake Tana. Initially the existence of water hyacinth was recorded in small area. Over the last ten years, the weed has shown substantial invasion on the normal land use land cover classes. The coverage of water hyacinth was in continuous increment from its commencement until now. The management interventions practiced by government and civil organizations have failed to halt the proliferation of the weed to the nearby areas. Figure 2 below displayed some part of water hyacinth cover in Lake Tana.

Statistics was computed to analyze the coverage of land use land cover types including water hyacinth. Table 2 below presents the area coverage of land use land cover classes. The water hyacinth coverage had a variation across the year from 0.17% up to 0.63% of the study area. The weed had a maximum coverage in the winter (15.35 km^2) while the minimum was recorded in autumn (4.14 km^2). On average, the water hyacinth had a spatial coverage of 11.22 km^2 in the year 2019. The high coverage of water hyacinth in winter was in contrast to Kibret and Worqlul (2018) which stated the wild expansion of the weed coverage in Lake Tana at wet seasons and reaching a peak in October (Spring). The possible reason for the contrast could be the management practices held by stakeholders (government and community). The extent of weed coverage difference was mainly driven from two reasons: climatic suitability and water hyacinth management. The extent of the weed becomes high when the climate is suitable for the weed's proliferation and when the management initiative is poor.

The water hyacinth area coverage on the summer, spring, winter and autumn seasons was identified and the output represents the three months in each season to estimate the water loss on Lake Tana. This is due to the relative similarity of climatic factors that determine the weed's proliferation. Dersseh et al. (2019) has pointed out that climate and water are governing conditions for the growth of water hyacinth. Numbers on the spatial coverage of water hyacinth across the four seasons does not imply the proliferation capacity of the weed. Because external factors like management of the weed practiced by stakeholders at different times of the year affect the coverage. Unfortunately, there is no well-organized data on the area of land cleared from Lake Tana. Thus, it is not possible to analyze the spatial coverage difference across seasons.

Figure 2. Water hyacinths around Lake Tana (Photo credit: Yilebes A.D, 2019).

Table 2. Spatial coverage of water hyacinth in 2019 across seasons.

Season	Water Hyacinth		Water		Others		Total	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Winter	15.35	0.63	2212.55	91.01	203.16	8.36	24310.66	100
Autumn	4.14	0.17	2211.00	90.94	216.24	8.89	24313.84	100
Summer	11.82	0.49	2214.13	91.07	205.23	8.44	24311.85	100
Spring	13.59	0.56	2236.42	91.98	181.35	7.46	24313.60	100
Mean	11.22	0.46	2218.53	91.25	201.50	8.29	24312.49	100

Source: Authors production, 2020.

The maximum likelihood land use land cover analyses of the study area, Lake Tana, have also delivered satellite image maps. Figure 3 below shows the water hyacinth spatial distribution in Lake Tana based on the reclassified land use land cover images on the four seasons of Ethiopia.

3.2. Accuracy assessment of the seasonal land use land cover classification images

The classification accuracy assessment was conducted to assess the accuracy of maximum likelihood classifications. In this study, accuracy assessment was performed for the classified maps of all the four seasons of 2019. Confusion matrices were used to assess classification accuracy using four measures of accuracy: user's accuracy, producer's accuracy, overall accuracy and Kappa statistic. The accuracy of the classified images was checked using ground truth region of interest (ROI). The land use land cover classes ROIs were crosschecked using ground observation and using Google earth engine. Sufficient accuracy assessment ROI pixels were taken from each land use land cover type for the analysis.

The overall accuracy and kappa analysis were used to perform a classification accuracy assessment. Accordingly the overall accuracy of the data were 95.11%, 99.41%, 99.07% and 99.77% and overall kappa coefficients were 0.93, 0.99, 0.98 and 0.97 for the winter, autumn, summer and spring 2019 images respectively. In addition, the user and producer accuracies have shown good outcomes. The ranges of producer accuracies were from 91.95% to 100%, 98.16% to 100%, 83.82% to 100% and 90.72% to 100% for the winter, autumn, summer and spring images respectively. On the other side, the user accuracies were found from 66.81% to 100%, 94% to 100%, 83.82% to 100% and 78.11% to 100% for similar order of images.

The confusion matrix results for the 2019 seasonal land use land cover classification images were within the acceptable 85% accuracy result (Anderson, 1971). The kappa values on the other hand were in the range of almost perfect classification (0.81–1.00) according to Landis and Koch (1977). The confusion matrix output can be generalized as the classified images are accurate and can be used up for further analysis. The results of overall accuracy and kappa value results are presented in Figure 4. The accuracy assessment result of this study is better than the overall accuracy of 84.11%–97.04% and kappa value of 0.80–0.96 which is reported by Sasaqi et al. (2019) using Landsat 8 image in their water hyacinth caused water loss study in Batujai Village, West Praya, Central Lombok, West Nusa Tenggara.

3.3. Estimation of water loss due to water hyacinth

Many tropical and subtropical regions in the world have water hyacinth problems. Especially in water reservoirs one of the main reasons for controlling this aquatic weed is its supposed high water consumption. Because of the high costs attendant on its eradication a good estimate of

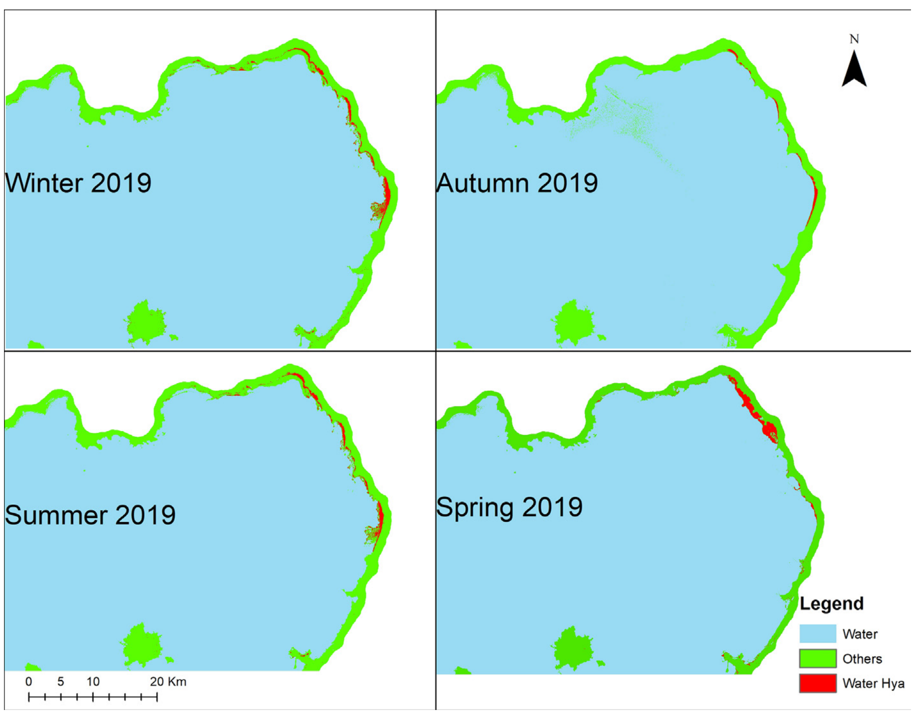

Figure 3. Water hyacinth coverage on Lake Tana over the 2019 seasons. Source: Authors production using MLC, 2020.

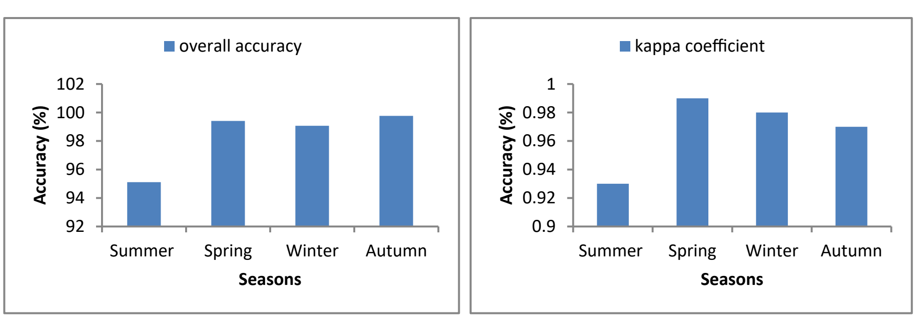

Figure 4. Overall accuracies (A) and Kappa values (B) for 2019 seasonal images. Source: Authors production from confusion matrix, 2020.

the transpiration losses should be made (Van der Weert and Kamerling, 1974). Water hyacinth increases evapotranspiration well above that of open water (often over 3 times "open pan" evaporation) thus causing significant water loss to dams, reservoirs and wild waters (IUCN, n.d.). The results vary considerably from study to study, but all studies indicate that the evapotranspiration from water hyacinth cover is higher than from open water (Herfjord et al., 1994). Some authors found that water lost by evapotranspiration is about 3.2–3.7 times the evaporation from a free water surface (Van der Weert and Kamerling, 1974).

Though the topic has been discussed for a long time, there are still unresolved questions on the effect of water hyacinth invasions on the evapotranspiration from a reservoir or other large water bodies. It should be an excellent field for research at a university or research institution in a tropical area (Herfjord et al., 1994). The study tried to estimate the water loss on the largest water source in Ethiopia, Lake Tana, due to the presence of water hyacinth weed.

Evaporation data was a prerequisite to estimate water loss. The pan evaporation data of National Meteorology Agency West Amhara Meteorological Service Center was used as a representative of Lake Tana free water evaporation. The daily pan evaporation data collected by the center was converted into monthly data before the analysis. The average monthly evaporation was found 5.14 mm/day while the maximum was recorded in April (7.31 mm/day) whereas the minimum was in August (3.8 mm/day) (see Figure 5). The maximum and mean evaporation of

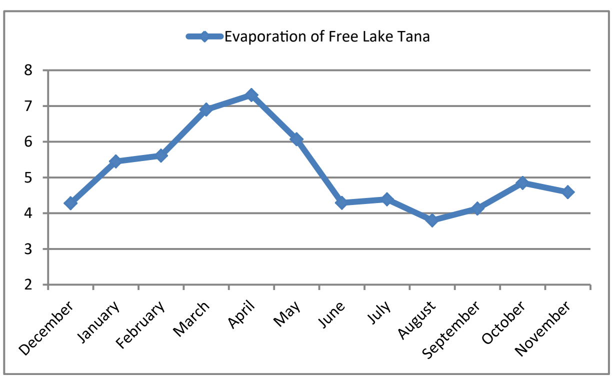

Figure 5. Mean daily evaporation of free Lake Tana in mm/day. Source: National Meteorology Agency, 2020.

Lake Tana is higher than 5 and 4.4 mm/day reported by Habib (2005) cited in: Yirefu et al. (2007) which is used to estimate the water loss effect in Wonji-Shewa Sugar Factory.

The water loss could be expressed in different time contexts. For this study, the water loss was estimated in a day, season and annual time periods. The net daily water loss due to water hyacinth existence in Lake Tana was calculated using the following equation.

$$NDWL = ((ET_{WH} - Ev) * \text{Area of Water Hyacinth})*10^{-9} \quad (4)$$

The mean net daily water loss in Lake Tana was 0.1447 km^3. The maximum and minimum mean net daily water loss was recorded as 0.2297 km^3 and 0.0670 km^3 in the months of February and May respectively. The net daily water loss in Lake Tana is a lot higher than 8,000 m^3 day-1 found from a water hyacinth coverage of 38,400 m^2–2,158,500 m^2 in Batujai Village, Praya Barat, Central Lombok, West Nusa Tenggara (Sasaqi et al., 2019). Moreover, the amount of water lost within a month was estimated by multiplication of net daily water loss and number of days in the month. The seasonal water loss was a summation of the losses within the season. The net seasonal water loss was high in winter (18.7811 km^3) while the lowest was recorded in autumn (6.8569 km^3). The total analysis result shows the net annual water loss due to water hyacinth weed mate in Lake Tana in 2019 was 52,6221 km^3. The annual water loss found in this study is by far higher than 393,660 to 2,945,160 m^3 from the 116.4 ha infestation on Wonji-Shewa sugar factory reported by Yirefu et al. (2007). Achieved results for the water loss estimation of water hyacinth are summarized in Table 3 below.

4. Conclusions and recommendations

The introduction of new species into a certain area can have adverse and positive effects on natural resources. This paper tried to capture the water hyacinth coverage and the amount of water loss per annum because of the existence of the water hyacinth on Lake Tana of Ethiopia in 2019. The remote sensing and classifications of the satellite imagery can be used as an economical and accurate way to produce accurate land use land cover maps in the Lake Tana. The accuracy assessment results of classified images were beyond the minimum level to accept the classifications.

The seasonal coverages of water hyacinth in 2019 were 15.35 km^2 (winter), 4.14 km^2 (autumn), 11.82 km^2 (summer) and 13.59 km^2 (spring) while the mean was 11.22 km^2. The open Lake Tana evaporation rate was found 5.14 mm/day on average. The mean net monthly and

Table 3. Summary of water loss of estimation in Lake Tana.

Season	Area of WH (km^2)	Month	Evaporation of free Lake (Ev)		Evapotranspiration of WH (ET_{WH})		Net water loss per day (km^3)	Net water loss per month (km^3)	No of days in the month	Seasonal water loss per season (km^3)
			Ev (mm/day)	Water loss Ev (m^3)	Ev (mm/day)	Water loss ETwh (m^3)				
Winter	15.3524	December	4.28	65708	15.69	240879	0.1752	5.4303	31	Winter 18.7811
		January	5.45	83671	19.99	306894	0.2232	6.9199	31	
		February	5.61	86127	20.57	315799	0.2297	6.4308	28	
Autumn	4.1374	March	6.9	28548	25.3	104676	0.0761	2.3600	31	Autumn 6.8569
		April	7.31	30244	26.81	110924	0.0807	2.4204	30	
		May	6.07	25114	22.26	92099	0.0670	2.0765	31	
Summer	11.8180	June	4.29	50699	15.73	185897	0.1352	4.0559	30	Summer 12.0572
		July	4.39	51881	16.1	190270	0.1384	4.2901	31	
		August	3.8	44908	13.93	164625	0.1197	3.7112	31	
Spring	13.5906	September	4.13	56129	15.14	205762	0.1496	4.4890	30	Spring 14.9270
		October	4.85	65914	17.78	241641	0.1757	5.4475	31	
		November	4.59	62381	16.83	228730	0.1663	4.9905	30	
	11.2246	**Mean**	**5.14**	**54277**	**18.85**	**199016**	**0.1447**	**4.3852**	**30.4**	**52.6221**

Kc-3.667.
Source: Authors production, 2020.

annual water losses caused by water hyacinth existence over Lake Tana were found as 4.39 km^3 and 52.62 km^3 while February and May have recorded the highest (0.2297 km^3) and lowest (0.067 km^3) net daily water loss.

Based on the results and conclusions of the study the following recommendations are generated for policy makers, practitioners and future research works.

- Efficient water hyacinth management initiatives shall be implemented to conserve Lake Tana water body that will help to achieve sustainability of the resource.
- Scholars should study the reason behind the seasonal variation of water hyacinth coverage. In addition, the spatial coverage difference of water hyacinth across seasons should be studied in controlled situations (experimental studies).
- Moreover, the water loss impact of water hyacinth should be further studied using on-spot floating pans on the Lake and the water hyacinth mats beside the meteorological data and application of constant coefficient of water hyacinth (Kc).

Declarations

Author contribution statement

Yilebes A. Damtie, Daniel Ayalew & Derege Meshesha: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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