International Journal of Natural Resource Ecology and Management
2023; 8(2): 38-48
http://www.sciencepublishinggroup.com/j/ijnrem
doi: 10.11648/j.ijnrem.20230802.11
ISSN: 2575-3088 (Print); ISSN: 2575-3061 (Online)

Monitoring of Water Surfaces in the Nakanbe-Wayen Watershed: Case of Bam and Dem Lakes in Burkina Faso

Wennepinguere Virginie Marie Yameogo[1, 2, *], Boalidioa Tankoano[1], Oumar Kabore[2], You Lucette Akpa[3], Zezouma Sanon[2], Farid Traore[2], Mipro Hien[1]

[1]Department of Environment Water and Forests, University Nazi Boni, Bobo Dioulasse, Burkina Faso

[2]Natural Resources Management Department, Institute of Environment and Agricultural Research (INERA), Ouagadougou, Burkina Faso

[3]Center for Research and Application in Remote Sensing (CURAT), University Felix Houphouet Boigny, Abidjan, Cote d'Ivoire

Email address:

kabyamvivi@gmail.com (Wennepinguere Virginie Marie Yameogo), oumarkabore@hotmail.com (Oumar Kabore), farid.traore@yahoo.fr (Farid Traore), zezoumasanon@yahoo.fr (Zezouma Sanon), btankus67@yahoo.fr (Boalidioa Tankoano), miphien@gmail.com (Mipro Hien), ylucetta@yahoo.fr (You Lucette Akpa)

[*]Corresponding author

To cite this article:

Wennepinguere Virginie Marie Yameogo, Boalidioa Tankoano, Oumar Kabore, You Lucette Akpa, Zezouma Sanon, Farid Traore, Mipro Hien. Monitoring of Water Surfaces in the Nakanbe-Wayen Watershed: Case of Bam and Dem Lakes in Burkina Faso. *International Journal of Natural Resource Ecology and Management*. Vol. 8, No. 2, 2023, pp. 38-48. doi: 10.11648/j.ijnrem.20230802.11

Received: March 30, 2023; **Accepted**: April 20, 2023; **Published**: May 10, 2023

Abstract: Spatial and temporal changes in the water surfaces of the Nakanbe-Wayen watershed influence, at the local and national levels, sustainable economic development. However, these changes in the basin remain poorly characterized. The present study, which aims at analyzing the spatio-temporal dynamics of the water surfaces of lakes Bam and Dem, two wetlands of international importance in the said watershed, exploited the processing power of the Google Earth Engine (GEE) platform to analyze 2121 Landsat image scenes over the period from 2000 to 2020. The water surfaces extraction algorithm, based on a combination of water and vegetation index, has been tested and adopted to rapidly extract the water surfaces of said wetlands. The results indicate that: (1) the water surfaces extraction method is well suited to that of Bam and Dem lakes; (2) the areas of water surfaces have a significant shrinking trend respectively -22.80 ha/year (P-value=0.0006) and -4.44 ha/year (P-value=0. 009) of the permanent surfaces of Bam Lake and Dem Lake from 2000 to 2020; (3) changes in the water surfaces of these lakes may be associated with climate change and human activities and should be studied in more detail. In view of the significant loss of water surfaces areas and the importance of lakes Bam and Dem for the communities and the environment, taking into account strong and concerted actions for restoration and conservation is urgent in order to perpetuate these natural spaces.

Keywords: Landsat, Google Earth Engine, Wetlands, Dynamics of Change, Burkina Faso

1. Introduction

Water is the major functional driver of wetlands [1]. This resource is extremely important for the promotion sustainable development, especially in the semi-arid Sahelian countries of West Africa. As essential components and key indicators of water resources [2], surface waters, especially those of wetlands, provide a range of ecosystem services such as water supply and regulation, climate regulation and food production [3]. However, they are undergoing remarkable changes, such as the deterioration of their quality, the sharp decline in their volume and the shrinkage of their surface area [4-7].

The surface water resources of Burkina Faso, in particular those of the watershed of the Nakanbé River, one of the most important rivers in the country, are not immune to this observation. The changing hydrological conditions since the last century threaten the economy and ecology of this watershed [8]. In these conditions of vulnerability of the local populations, it is more than important to have more in-depth knowledge on the spatio-temporal dynamics of the water surfaces in order to ensure a sustainable management of these water resources. Nowadays, remote sensing permits to follow these spatio-temporal changes [9, 10]. Indeed, studies on the changes of water surfaces in the Nakanbe-Wayen basin have been conducted using MODIS and TerraSAR-X images [11]. However, these studies have used medium resolution and epoch-based images because it is difficult to process huge amounts of remote sensing data [12]. In the study area, there have been no studies of water surface dynamics based on a long series of high-resolution satellite images. Yet, due to the dynamics of surface waters, such studies based on high temporal resolution of satellite images, could provide more information to monitor the changes of water surfaces. The Google Earth Engine (GEE) platform offers a promising solution for processing large volumes of data or "big data" [13-15]. It has been widely used in many studies, especially wetlands mapping [13, 16-19]. It offers efficient computing performances in terms power and time [2, 12, 13]. Therefore, GEE is like a good tool to understand the long-term changes of water surfaces [2].

Thus, this study aims at (1) adapting a new framework for rapid and automated detection of wetland water surfaces, (2) analyzing long-term changes from 1991 to 2020, (3) improving knowledge of surface water body dynamics.

2. Material and Methods

2.1. Study Area

Lake Bam covers an area of about 2.350 ha in high water period [20]. Its watershed, located in the province of Bam, covers 2.610 km² [21]. Lake Bam, the largest natural and permanent lake in Burkina Faso [22], is the economic lung of the North-Central region. It has been a Ramsar wetland of international importance since 2009 [23] and an important habitat for many species of birds, fish and the Nile crocodile [20]. Water is abstracted for irrigation. In addition, fishing and livestock farming are highly developed there.

Lake Dem is a natural lake, with an area of 750 ha and extends over a length of about 20 km at high water [24]. The water is not only withdrawn for irrigation but also for the drinking water supply for the town of Kaya, located about 10 km from the lake [20]. Other activities include fishing and livestock breeding [24]. It plays a very important role in the conservation of biodiversity, especially avian and aquatic biodiversity. The lake has been designated a Ramsar site since 2009.

Both sites belong to the Nakanbe-Wayen watershed, a sub-watershed of the Nakanbe River. The Nakanbe River is the second most important river in the country after the Mouhoun River.

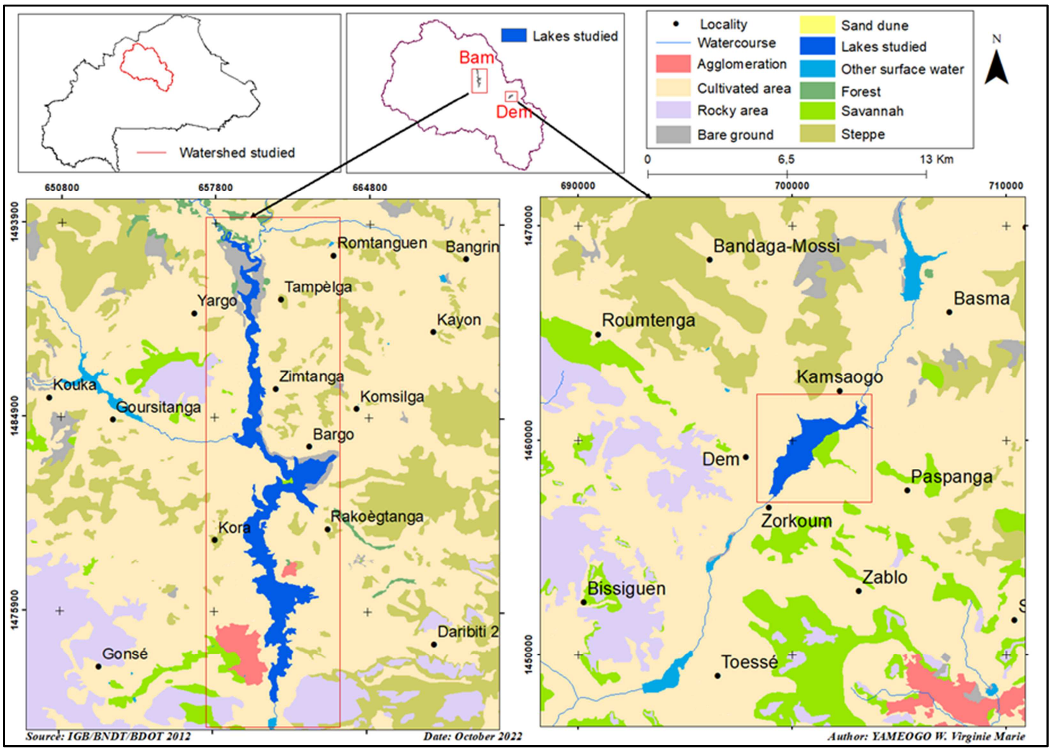


Figure 1. *Location of study sites.*

2.2. Data and Acquisition Sources

2.2.1. Landsat Images

Surface water bodies have significant seasonal and intra-annual variations. Therefore, in order to gather more information on their dynamics, all Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI images of the collection 2 [1] covering the study area, over the period from 2000 to 2020

1 Collection 2: second major reprocessing campaign on the Landsat archive, released in December 2020 by the USGS. Collection 2 processing has resulted in several data product improvements that exploit recent advances in data processing, algorithm development, and data access and distribution capabilities.

were collected on the Google Earth Engine platform (https://earthengine.google.org/). A total of 2121 Landsat 5, 7, and 8 images from Collection 2 (Figure 2), with a spatial resolution of 30 m and were used as a data source for the detection and extraction of surface water bodies.

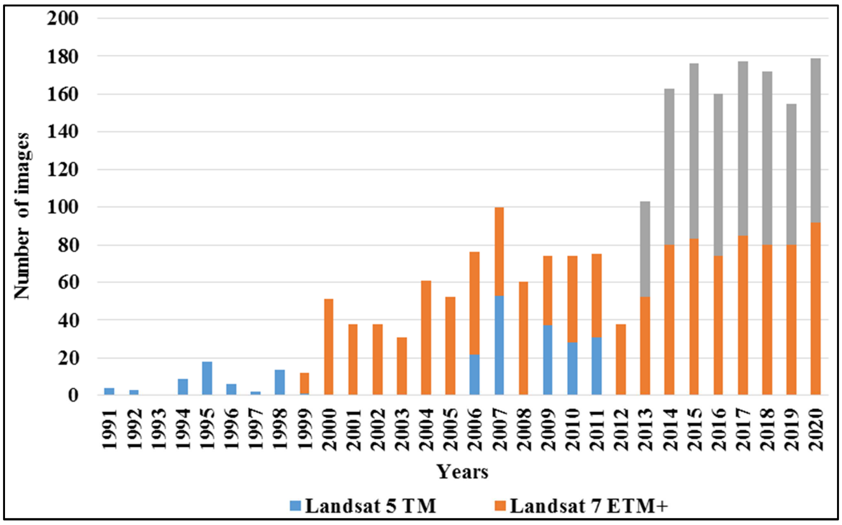


Figure 2. *Annual distribution of Landsat images.*

Landsat images from Collection 2 have been subjected to geometric and atmospheric correction, as well as cross-calibration between different sensors [25, 26], which improves the detection and characterization of surface changes. Landsat images were chosen for this study because they offer high spatial and temporal resolution data, open and free access, and having the longest time series [27-30] allowing the monitoring of wetlands.

2.2.2. Sentinel-2 Multispectral Instrument (MSI) Images

All images Sentinel-2 MSI images, 10 m spatial resolution from the year 2020, with less than 10% cloud cover were selected to assess the accuracy of extracting water surfaces of Bam and Dem Lakes wetlands.

2.3. Processing and Analysis Methods

2.3.1. Data Preparation

In an effort to improve the quality of the series images and the efficiency of the calculation, a series of pre-processing was applied to all the collected images. First, the images with cloud cover less than or equal to 15% were selected. Then, we applied a cloud mask to each of these images, using the "Fmask" function of GEE in order to remove residual clouds (as well as cloud shadows) from the collected images. This algorithm was built based on the quality band of Landsat surface reflectance products [18, 30, 31]. Pixels disabled from the scan line correction (SLC) of the Landsat ETM+ dataset, were treated as clouds or shadows by the same "Fmask" function [31], their impact was found to be limited on the analysis of time series analysis [7, 31]. Thus, unmasked pixels were considered good observations. Six spectral bands, including blue, green, red, near-infrared, shortwave infrared 1, and shortwave infrared 2, were used to extract water surfaces.

2.3.2. Detection, Extraction and Frequency of Water Presence

Due to the mixed distribution of water and vegetation likely to exist in wetlands, water surfaces can be detected using the relationships between water and vegetation indices [18]. Water index, such as modified normalized difference water index (mNDWI) and vegetation indices such as enhanced vegetation index (EVI) and normalized difference vegetation index (NDVI), which equations are as follows (1 to 3), were used in the algorithm proposed by Zou et al [32] and was adapted for this study, to extract the open water surfaces of these wetlands areas.

$$mNDWI = \frac{\text{Green} - \text{SWIR1}}{\text{Green} + \text{SWIR1}} \quad (1)$$

$$NDVI = \frac{PIR - Red}{PIR + Red} \quad (2)$$

$$EVI = 2.5 * \frac{\text{PIR} - \text{Red}}{(\text{PIR} + 6 * \text{Red} - 7.5 * \text{Blue} + 1)} \quad (3)$$

Where Red, Green, Blue, PIR, and SWIR1 are the reflectance of the Red band (0.63-0.69 µm), Green band (0.52-0.6 µm), Blue band (0.45-0.52 µm), Near Infrared band (0.77-0.9 µm), and SWIR1 band (1.55-1.75 µm), respectively. 2.5 is the gain factor, 1 is the soil adjustment factor, and 6 and 7.5 are the atmospheric scattering correction coefficients.

This algorithm has been shown to be effective in many studies [2, 12, 18, 33-35], with an overall accuracy of more than 96%. Its equation is as follows:

$$\text{mNDWI} > \text{NDVI and EVI} < 0.1 \text{ or}$$
$$\text{mNDWI} > \text{EVI and EVI} < 0.1 \quad (4)$$

The criterion mNDWI>EVI or mNDWI>NDVI identifies pixels that have a stronger water signal than the vegetation signal. EVI<0.1 can ensure that vegetation pixels or mixed water and vegetation pixels have been eliminated.

Therefore, only pixels meeting the (4) criteria were classified as water pixels. This algorithm is effective for mapping surface waters [17, 32]. In addition, it has been tested by several other authors [2, 12, 18, 33-35] and has given good results (Kappa coefficient between 85 and 90%).

The water frequency index (Feau) was used to analyze the spatio-temporal dynamics of open water surfaces in the wetlands of Bam and Dem lakes. This index is defined as the percentage of water observations out of all good observations [2, 18, 36, 37]. For each detected water pixel, its frequency over a year was calculated using equation (5):

$$F_{water} = \frac{\sum N_{water}}{\sum N_{total}} \quad (5)$$

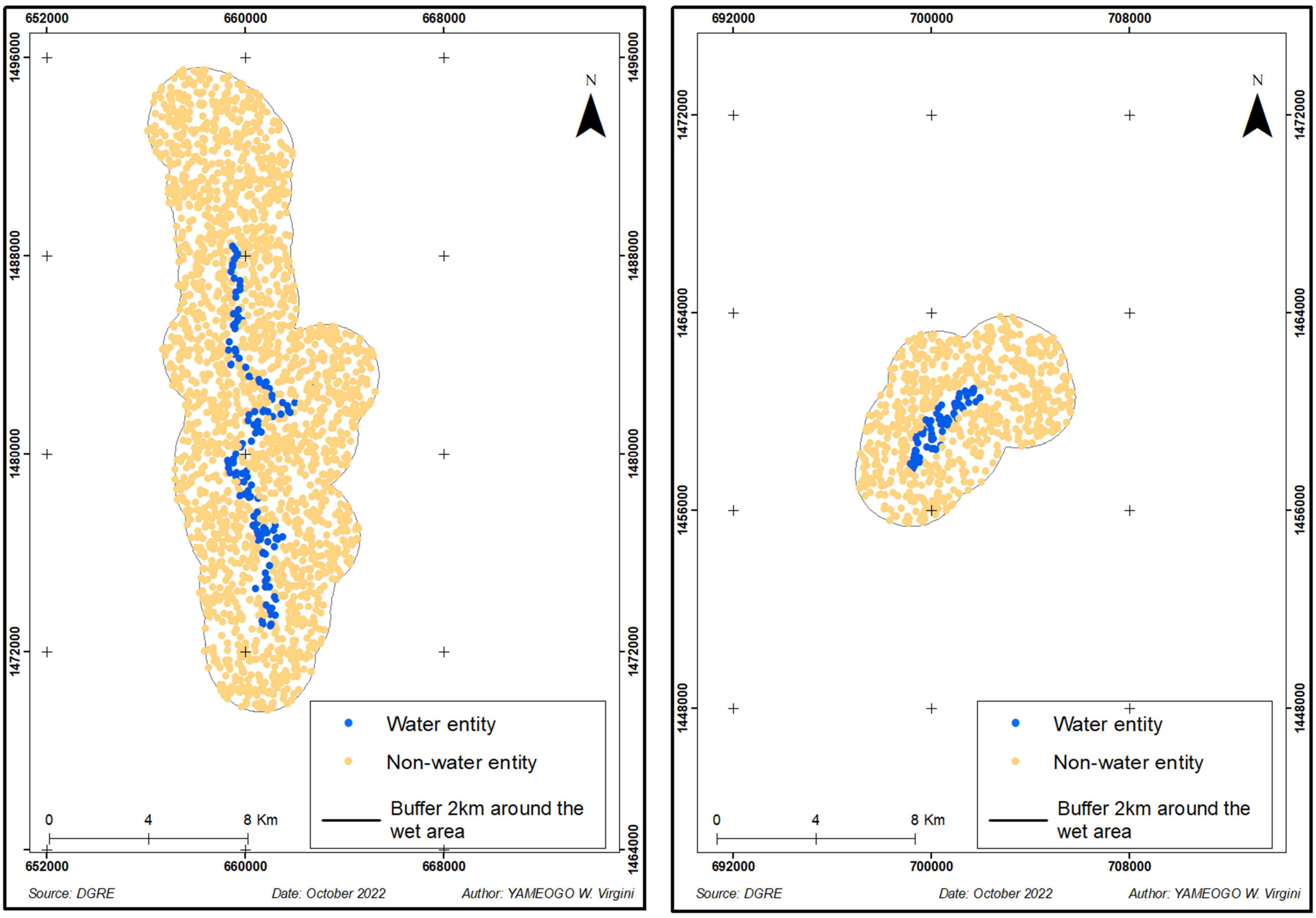
Where F_{Water}, between 0 and 1 is the frequency of water over a given period. N_{water} represents the number of times a pixel is classified as water in a given period, and N_{total} represents the total number of pixels of good observations in a given period.

Based on the one-year water frequency index (F_{Water}), the water pixels were classified into three classes. Seasonal water areas with F_{Water} between [0.25-0.75], permanent water areas with F_{Water} between [0.75-1] and maximum water areas, representing the accumulation of permanent and seasonal water [17, 32, 34]. The frequency between [0-0.25] is considered to be the "No Water" class.

2.3.3. Evaluation of the Accuracy of Water Surfaces Extraction

Open water surfaces mapping of the two wetlands (Lake Bam and lake Dem) was generated using the Landsat images, an open water extraction algorithm, and the GEE platform mentioned above. The stratified random sampling approach and very high resolution Sentinel-2 images were used to assess the accuracy of the open water surface map in 2020. The Sentinel-2 images were subjected to the same selection conditions as Landsat [2], i.e., having less than 15% cloud cover. A total of 409 Sentinel-2 images were used to serve as data for the validation of the water surface extraction map. First, the study area was divided into two strata water and non-water. Then, random points were generated in each stratum using QGIS software and then supplemented with ground truth points. A total of 1597 points were generated for the validation of the two strata: water (275 points) and non-water (1322 points). A confusion matrix, with producer accuracy (PA), user accuracy (UA), overall accuracy (OA) and Kappa coefficient (Kc) was calculated to assess the accuracy of the results.

Figure 3 (Figure 3a and Figure 3b) shows the spatial distribution of the validation sample.



a. Lake Bam *b. Lake Dem*

Figure 3. *Spatial distribution of the validation sample.*

2.3.4. Statistical Analysis of the Spatial and Temporal Dynamics of Surface Waters

A set of descriptive statistics tests was used to analyze the variations. The trend analysis of the water surfaces of the lakes Bam and Dem wetlands was done using a linear regression method, composed of the Mann-Kendall (Mann, 1945; Kendall, 1975) and Sen [38] tests. This is a non-parametric method of robust linear trend regression [33, 38-41], recommended by the World Meteorological Organization (WMO). It is used to test for the presence or absence of trend and to estimate the slope associated with the trend in time series [42]. This method is widely used in hydrological time trend studies [42-48].

2.3.5. Analysis Tools

Most of the processing was performed on the Google Earth Engine platform (https://developers.google.com/earth-engine/), which has great power for storing and processing remote sensing data [2, 12, 13]. All statistical analyses were performed using R software, and the maps were edited using QGIS.

3. Results

3.1. Assessing the Accuracy of the Extraction of the Surface Water Bodies

Table 1 shows the extraction accuracy of the surface water bodies of lakes Bam and Dem. The user and producer accuracies are 94.08% and 98.18% respectively. At the same time the overall accuracy and kappa coefficient, which are also respectively high 97.87% and 95.67%. These results show that the surface waters extraction is consistent with the ground truth. That is why, we estimate that the algorithm of Zou et al. (2017) is also well suited for the extraction of open water surfaces in the said study area.

3.2. Analysis of the Spatio-Temporal Dynamics of the Water Surfaces of Lake Bam

Figure 4 shows the spatial distribution of the water surfaces of the Bam Lake wetland. This is the maximum and minimum range of the period from 2000 to 2020, as well as the historical average of that period.

Compared to the historical average of the series (Figure 4c), the relatively low water frequency values at the edges and the northern part of the lake tend to disappear over the years, and a shrinkage of the central part is observed (Figure 4a) and Figure 4b). Also, during this period, the water surfaces of the Lake Bam wetland have varied up and down from one year to another. The seasonal area recorded the most variation with a coefficient of variation of 48.04%, followed by the permanent area with a coefficient of variation of 25.26%. The maximum area is the one that has varied less in the period, with a coefficient of variation of 20.23%. The summary of water surfaces is presented in Table 1.

Table 1. *Confusion matrix.*

Landsat	Sentinel 2			
	Water	**No water**	**Total**	Producer Accuracy (PA)
Water	270	5	275	98.18
No water	17	1305	1322	98.71
Total	287	1310	1597	Overall accuracy (OA) = 97.87
User's accuracy (UA)	94.08	9.62		Kappa coefficient = 95.67

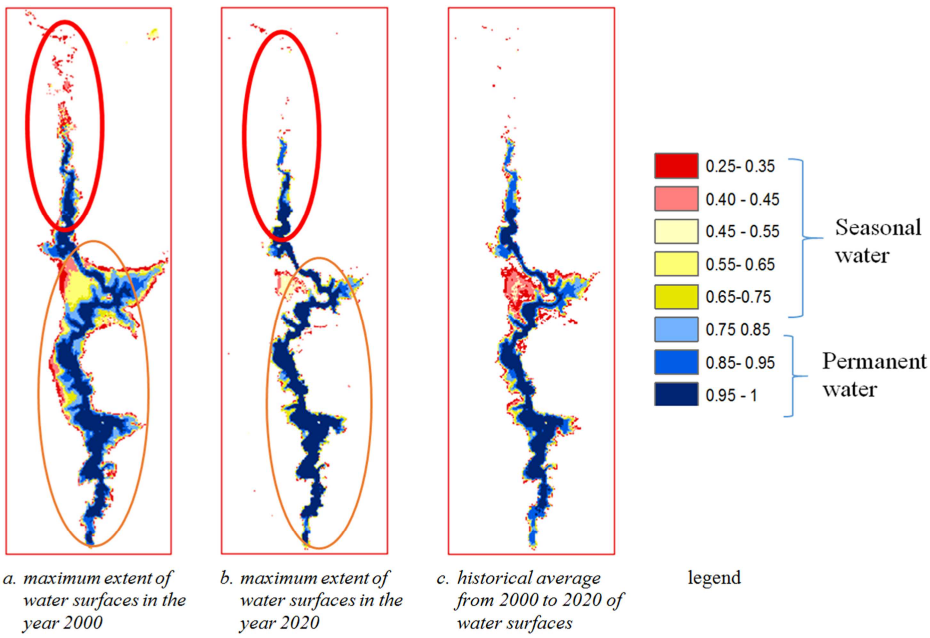
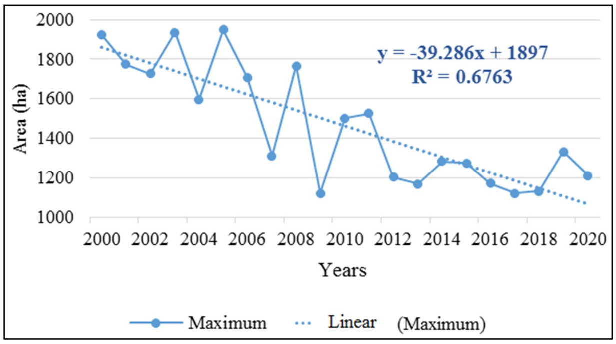


Figure 4. *Spatial distribution of water surfaces in Lake Bam from 2000 to 2020.*

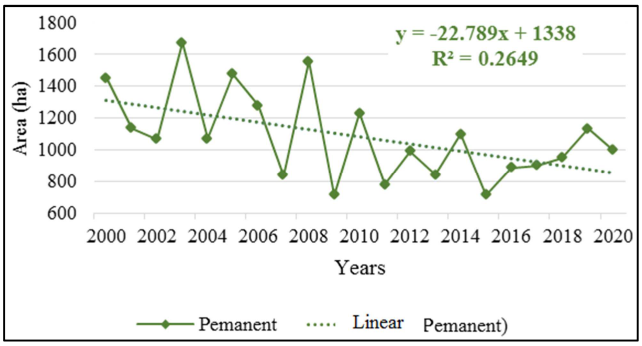
***Table 2.** Summary of water surfaces (ha) of the Bam Lake wetland from 2000 to 2020.*

Area	Minimum	Average	Standard deviation	Coefficient of variation	Maximum
Maximum	1123.07	1464.80	296.40	20.23	1947.73
Permanent	715.85	1087.30	274.73	25.26	1673.88
Seasonal	176.24	373.45	179.40	48.04	743.60

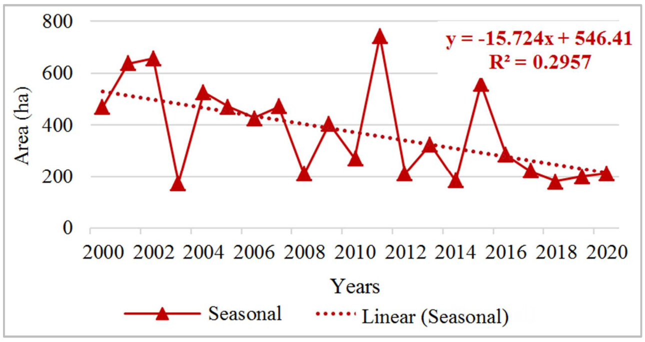
The trend analyses of the water surfaces of Lake Bam show a significant downward trend for all the water surfaces of the said wetland (Figure 5), with a rate of decrease of -22.80 ha/year (P-value=0.0006) and -15.72 ha/year (P-value=0.0108) of -39.29 ha/year (P-value=0.000005) respectively for the permanent (Figure 5b), seasonal (Figure 5c), and maximum (Figure 5a) water surfaces.



a. Maximum water surface



b. Permanent water surface

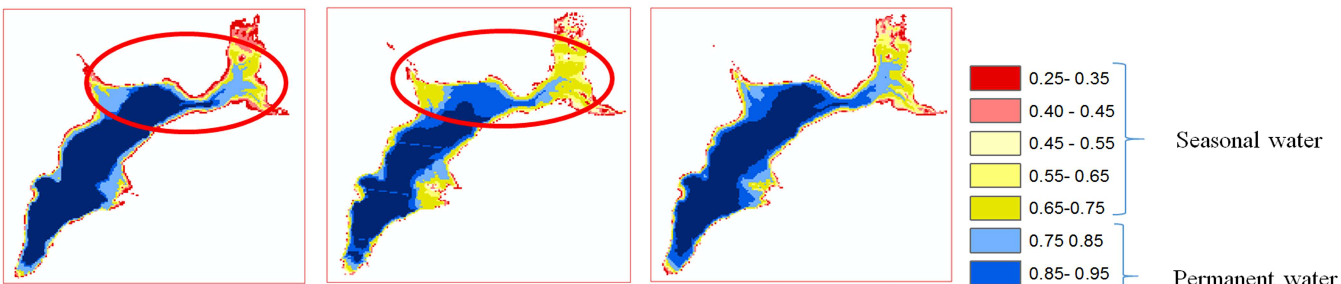


c. Seasonal water surface

***Figure 5.** Assessment and trend of the water surfaces of Bam Lake.*

3.3. Analysis of the Spatio-Temporal Dynamics of the Water Surfaces of the Lake Dem

Figure 6 presents the spatio-temporal distribution of the water surfaces of the wetland of "Dem Lake". A shrinking of the permanent water surface of the edges is observed in general, with a remarkable shrinking of the North-East part of the Dem Lake. This illustrates well the tendency to the seasonality of the lake.



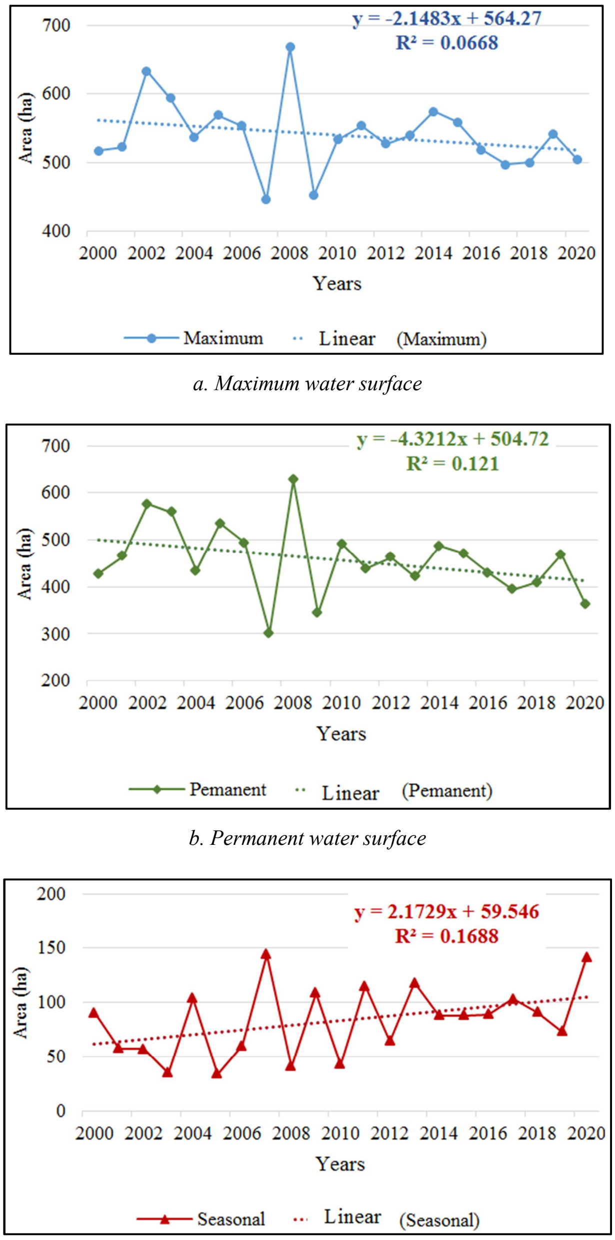
a. water surface area in the year 2000 *b. water surface area in the year 2020* *c. historical average surface area from 2000 to 2020*

***Figure 6.** Spatial distribution of the water surfaces of lake Dem wetland from 2000 to 2020.*

Also, the water surfaces of the lake varied from one year to the other during the period 2000 to 2020. The seasonal surface recorded the most variation with a coefficient of variation of 39%, followed by the permanent surface with a coefficient of variation of 16.86%. The maximum surface has varied less in the period, with a coefficient of variation of 9.53%. The summary of the water surfaces is presented in Table 3.

Table 3. *Water surfaces area (in ha) of the "Dem Lake" wetland from 2000 to 2020.*

Area	Minimum	Average	Standard deviation	Coefficient of variation	Maximum
Maximum	446.27	540.63	51.56	9.53	668.08
Permanent	301.92	457.19	77.08	16.86	626.92
Seasonal	34.31	83.44	32.81	39	144.34



a. Maximum water surface

b. Permanent water surface

c. Seasonal water surface

Figure 7. *Assessment and trend of the water surfaces of Dem Lake.*

The results obtained from the linear regression models show a significant downward trend in the permanent water surface (Figure 7a) of -4.44 ha/year (P-value=0.009) and a significant upward trend in the seasonal water surface (Figure 7c) of 2.12 ha/year (P=0.001) per year. The maximum area has a decreasing trend (Figure 7a) of -2.27 ha/year (P-value =0.086), with a significance level of 10%.

4. Discussion

4.1. Spatial and Temporal Dynamics of the Water Surfaces of the Watershed

The spatio-temporal dynamics of the water surfaces of lakes Bam and Dem show a significant (P-value < 0.05) trend of shrinkage during 2000 and 2020. These results corroborate the study of Moser et al. (2014), based on medium optical resolution time series (2000 to 2014), which detects strong negative trends in the water surfaces of these lakes. This trend towards shrinking of the water resource surfaces conditions, threaten the sustainability of these wetland ecosystems [8, 49]. At the current rate of change, these lakes are threatened with extinction. According to CINTECH [50], Lake Dem, with an area of 778.35 ha in 1992, has been decreased to an area of 551.08 ha in 2012, resulting in a reduction rate of approximately 30% of its area in 20 years.

The loss of water surfaces and especially those of lakes is common to many countries. In Africa, most of these wetlands are considered as endangered ecosystems [51]. Riddell et al [52] highlighted a loss of about 30-60% of wetlands in South Africa. The same observation has been made in Sub-Saharan Africa [53]. Several authors agree that the loss of wetland water surfaces is the combined result of natural and anthropogenic factors [54-61].

Most of the country's water resources come exclusively from precipitation, one of the climatic factors that have a significant impact on surface water changes [62]. Thus, the high inter-annual variability of precipitation from one year to another recorded in the watershed influences the availability of already limited water resources [63]. Also, surface waters are increasingly subject to a higher evaporation in continuous growth, consecutive to the rise in temperature [64]. Moreover, according to [65] the annual average of the evaporation is more than 2000 mm, thus losing more than 60% of the water in the surface reservoirs. In addition, the increasing trend of extreme events, recorded with global warming [66], such as the increase in the intensity and occurrence of intense rainfall, accentuated by the fragility of the sloping soils [67], accelerates water erosion, with the consequence of the sedimentation (silting) of water bodies [68] which is felt in a disturbing way, at the level of lakes Bam and Dem [69].

Ouedraogo [70] shows that Lake Bam lost one-third (1/3) of its depth between 1963 and 2006. In addition, the rise in temperatures combined with the increase in rainfall variability also leads to an increase demand in water for irrigation [35]. Knowing that the waters of the lakes are mainly used for agriculture, the increased withdrawal of water for irrigation purpose leads to a decrease in surface waters area.

This climatic pressure is exacerbated by unsustainable water resource use and management practices, which are closely linked to population growth. These resources are subject to unprecedented overexploitation, resulting in a perpetual increase in the demand for water for the various needs (drinking, agricultural, industrial, etc.) of the populations whose numbers are constantly growing [63, 71]. Also Serpantie and Zombre [72] assert that wetlands have played an increasing agricultural role there since the droughts of the 1970s and 1980s in Burkina Faso.

Clearly, spatio-temporal changes in surface water bodies have a profound influence on sustainable economic development [2], exacerbating the vulnerability of the populations that depend on them, all the more as the level of development is closely dependent on natural resources [73-76]. Therefore, a sustainable management of these spaces of these wetland ecosystems is recommended, in order to guarantee their accessibility to the populations for their multiple uses.

4.2. Limitation of the Research

The Google Earth Engine platform was mainly used to analyze of the dynamics of water surfaces of lakes Bam and Dem. This platform is quite user-friendly, for processing large volumes of data or "big data" of remote sensing. However, knowledge of JavaScript or Python programming language is required. This remains the main limitation of the use of this platform. Also, the annual availability of Landsat images prior to the year 2000 over the study area does not meet the conditions of at least one image per month (of which cloud cover is less than 15% cloud cover). This was a limitation in the choice of the period. In addition, the spatial resolution of 30 m could omit minute changes in water surfaces. Therefore, a higher spatial resolution, such as Sentinel-2 images, could be considered to fill this gap. However, many satellites providing very high resolution images have only recently been put into orbit. This is the case of Sentinel-2, which was launched in 2015.

5. Conclusion

This study examined the spatio-temporal changes in the water surfaces of lakes Bam and Dem wetlands of the Nakanbe-Wayen basin over the period from 2000 to 2020. All Landsat TM, ETM+ and OLI images covering the study area and available in the Google Earth Engine (GEE) platform over this period were used. The spatio-temporal dynamics of the water surfaces of the wetlands of Bam and Dem lakes in the basin were analyzed via a water extraction algorithm based on a combination of water and vegetation index, using the Google Earth Engine platform. Better accuracies were obtained, with Kappa coefficient of 95.6% and an overall accuracy is 97.87%, demonstrating that the method of extracting water surfaces adopted is as effective and suitable for the Bam and Dem lakes watersheds.

The analysis results show that the water surfaces of the wetlands have undergone major changes between 2000 and 2020, with a significant trend (P-value < 0. 05) towards a decrease in water surfaces. At the current rate of their evolution, these lakes are at high risk of disappearing if strong and concerted actions are not taken to reverse this trend.

This study raises the alarm for politicians and managers on the necessity and urgency to preserve the potential of Bam and Dem lakes which contribute enormously to the socio-economic development of the area in particular and the country in general. This is why, following this study, we recommend the development of an appropriate and anticipated water resource management strategy at the watershed level. This should be formulated in a participatory scheme, involving all stakeholders, integrating science, governance, society and focusing on the availability of water resources. In perspective, this study should be completed by a climate risk analysis on the water resource of the said watershed.

References

[1] J.-L. Michelot, *Les zones humides et l'eau*, BRGM. Paris 07 SP ed. Paris, 2003.

[2] Y. Deng, W. Jiang, Z. Tang, Z. Ling, and Z. Wu, "Long-Term Changes of Open-Surface Water Bodies in the Yangtze River Basin Based on the Google Earth Engine Cloud Platform," *Remote Sensing,* vol. 11, p. 2213, 2019.

[3] A. P. Wood, A. Dixon, and M. P. McCartney, *Wetland management and sustainable livelihoods in Africa*: Routledge/Earthscan from Routledge, 2013.

[4] E. Maltby, D. Hogan, and R. Mclnnes, "The function of river marginal wetland ecosystems," *Improving the science base for the development of procedures of functional analysis. Final report to the European Union for project EC DGXII CT90-0084,* 1996.

[5] W. Junk, S. An, M. Finlayson, B. Gopal, J. Květ, S. Mitchell*, et al.*, "Current state of knowledge regarding the world's wetlands and their future under global climate change: A synthesis," *Aquatic Sciences,* vol. 75, pp. 151-167, 01/01 2013.

[6] N. C. Davidson, "How much wetland has the world lost? Long-term and recent trends in global wetland area," *Marine and Freshwater Research,* vol. 65, pp. 934-941, 2014.

[7] Z. Zhu, "Change detection using landsat time series: A review of frequencies, preprocessing, algorithms, and applications," *ISPRS Journal of Photogrammetry and Remote Sensing,* vol. 130, pp. 370-384, 2017.

[8] SP/CNDD, "Le quatrième rapport sur l'état de l'environnement au Burkina Faso (REEB IV) " 2018.

[9] Q. Huang, D. Long, M. Du, C. Zeng, G. Qiao, X. Li*, et al.*, "Discharge estimation in high-mountain regions with improved methods using multisource remote sensing: A case study of the Upper Brahmaputra River," *Remote Sensing of Environment,* vol. 219, pp. 115-134, 2018/12/15/ 2018.

[10] S. Hu, J. Qin, J. Ren, H. Zhao, J. Ren, and H. Hong, "Automatic Extraction of Water Inundation Areas Using Sentinel-1 Data for Large Plain Areas," *Remote Sensing,* vol. 12, p. 243, 2020.

[11] L. Moser, A. Schmitt, A. Wendleder, and A. Roth, "Monitoring of the Lac Bam Wetland Extent Using Dual-Polarized X-Band SAR Data," *Remote Sensing,* vol. 8, p. 302, 04/05 2016.

[12] C. Wang, M. Jia, N. Chen, and W. Wang, "Long-Term Surface Water Dynamics Analysis Based on Landsat Imagery and the Google Earth Engine Platform: A Case Study in the Middle Yangtze River Basin," *Remote Sensing,* vol. 10, p. 1635, 2018.

[13] N. Gorelick, M. Hancher, M. Dixon, S. Ilyushchenko, D. Thau, and R. Moore, "Google Earth Engine: Planetary-scale geospatial analysis for everyone," *Remote Sensing of Environment,* vol. 202, pp. 18-27, 2017/12/01/ 2017.

[14] H. A. Zurqani, C. J. Post, E. A. Mikhailova, M. A. Schlautman, and J. L. Sharp, "Geospatial analysis of land use change in the Savannah River Basin using Google Earth Engine," *International Journal of Applied Earth Observation and Geoinformation,* vol. 69, pp. 175-185, 2018/07/01/ 2018.

[15] O. Mutanga and L. Kumar, "Google Earth Engine Applications," *Remote Sensing,* vol. 11, p. 591, 2019.

[16] J.-F. Pekel, A. Cottam, N. Gorelick, and A. S. Belward, "High-resolution mapping of global surface water and its long-term changes," *Nature,* vol. 540, pp. 418-422, 2016/12/01 2016.

[17] Z. Zou, X. Xiao, J. Dong, Y. Qin, R. B. Doughty, M. A. Menarguez*, et al.*, "Divergent trends of open-surface water body area in the contiguous United States from 1984 to 2016," *Proceedings of the National Academy of Sciences,* vol. 115, pp. 3810-3815, 2018.

[18] Y. Zhou, J. Dong, X. Xiao, R. Liu, Z. Zou, G. Zhao*, et al.*, "Continuous monitoring of lake dynamics on the Mongolian Plateau using all available Landsat imagery and Google Earth Engine," *Science of The Total Environment,* vol. 689, pp. 366-380, 2019/11/01/ 2019.

[19] J. Bian, A. Li, G. Lei, Z. Zhang, and X. Nan, "Global high-resolution mountain green cover index mapping based on Landsat images and Google Earth Engine," *ISPRS Journal of Photogrammetry and Remote Sensing,* vol. 162, pp. 63-76, 2020/04/01/ 2020.

[20] L. Moser, S. Voigt, E. Schoepfer, and S. Palmer, "Multitemporal Wetland Monitoring in Sub-Saharan West-Africa Using Medium Resolution Optical Satellite Data," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* vol. 7, 08/11 2014.

[21] K. Drabo, J. Yameogo, and L. Sawadogo, "Examen de la gestion et stratégies de protection des berges du Lac Bam à Kongoussi au Centre-Nord du Burkina Faso," *Int. J. Biol. Chem. Sci,* vol. 10, pp. 944-956, 2016.

[22] N. Da, R. Ouédraogo, and A. Ouéda, "Relation poids-longueur et facteur de condition de Clarias anguillaris et Sarotherodon galilaeus pêchées dans le lac Bam et le réservoir de la Kompienga au Burkina Faso," *International Journal of Biological and Chemical Sciences,* vol. 12, pp. 1601-1610, 2018.

[23] SP/CNDD, "Fiche descriptive Ramsar Lac Bam Burkina Faso," Burkina Faso 2017.

[24] SP/CNDD, "Fiche descriptive Ramsar lac Dem Burkina FAso," 2017.

[25] M. A. Wulder, J. C. White, T. R. Loveland, C. E. Woodcock, A. S. Belward, W. B. Cohen*, et al.*, "The global Landsat archive: Status, consolidation, and direction," *Remote Sensing of Environment,* vol. 185, pp. 271-283, 2016/11/01/ 2016.

[26] J. L. Dwyer, D. P. Roy, B. Sauer, C. B. Jenkerson, H. K. Zhang, and L. Lymburner, "Analysis Ready Data: Enabling Analysis of the Landsat Archive," *Remote Sensing,* vol. 10, p. 1363, 2018.

[27] N. Pahlevan and J. R. Schott, "Characterizing the relative calibration of Landsat-7 (ETM+) visible bands with Terra (MODIS) over clear waters: The implications for monitoring water resources," *Remote Sensing of Environment,* vol. 125, pp. 167-180, 2012/10/01/ 2012.

[28] M. G. Tulbure, M. Broich, S. V. Stehman, and A. Kommareddy, "Surface water extent dynamics from three decades of seasonally continuous Landsat time series at subcontinental scale in a semi-arid region," *Remote Sensing of Environment,* vol. 178, pp. 142-157, 2016/06/01/ 2016.

[29] J. E. Vogelmann, A. L. Gallant, H. Shi, and Z. Zhu, "Perspectives on monitoring gradual change across the continuity of Landsat sensors using time-series data," *Remote Sensing of Environment,* vol. 185, pp. 258-270, 2016/11/01/ 2016.

[30] S. Foga, P. L. Scaramuzza, S. Guo, Z. Zhu, R. D. Dilley Jr, T. Beckmann*, et al.*, "Cloud detection algorithm comparison and validation for operational Landsat data products," *Remote sensing of environment,* vol. 194, pp. 379-390, 2017.

[31] Z. Zhu, S. Wang, and C. E. Woodcock, "Improvement and expansion of the Fmask algorithm: cloud, cloud shadow, and snow detection for Landsats 4–7, 8, and Sentinel 2 images," *Remote Sensing of Environment,* vol. 159, pp. 269-277, 2015/03/15/ 2015.

[32] Z. Zou, J. Dong, M. A. Menarguez, X. Xiao, Y. Qin, R. B. Doughty*, et al.*, "Continued decrease of open surface water body area in Oklahoma during 1984–2015," *Science of The Total Environment,* vol. 595, pp. 451-460, 2017/10/01/ 2017.

[33] Y. Wang, J. Ma, X. Xiao, X. Wang, S. Dai, and B. Zhao, "Long-Term Dynamic of Poyang Lake Surface Water: A Mapping Work Based on the Google Earth Engine Cloud Platform," *Remote Sensing,* vol. 11, p. 313, 2019.

[34] H. Xia, J. Zhao, Y. Qin, J. Yang, Y. Cui, H. Song*, et al.*, "Changes in Water Surface Area during 1989–2017 in the Huai River Basin using Landsat Data and Google Earth Engine," *Remote Sensing,* vol. 11, p. 1824, 2019.

[35] X. Wang, X. Xiao, Z. Zou, B. Chen, J. Ma, J. Dong*, et al.*, "Tracking annual changes of coastal tidal flats in China during 1986–2016 through analyses of Landsat images with Google Earth Engine," *Remote Sensing of Environment,* vol. 238, p. 110987, 2020/03/01/ 2020.

[36] N. Xu, "Detecting Coastline Change with All Available Landsat Data over 1986–2015: A Case Study for the State of Texas, USA," *Atmosphere,* vol. 9, p. 107, 2018.

[37] X. Wang, X. Xiao, Z. Zou, J. Dong, Y. Qin, R. B. Doughty*, et al.*, "Gainers and losers of surface and terrestrial water resources in China during 1989–2016," *Nature communications,* vol. 11, pp. 1-12, 2020.

[38] P. K. Sen, "Estimates of the Regression Coefficient Based on Kendall's Tau," *Journal of the American Statistical Association,* vol. 63, pp. 1379-1389, 1968/12/01 1968.

[39] A. F. Siegel, "Robust regression using repeated medians," *Biometrika,* vol. 69, pp. 242-244, 1982.

[40] K. C. Fickas, W. B. Cohen, and Z. Yang, "Landsat-based monitoring of annual wetland change in the Willamette Valley of Oregon, USA from 1972 to 2012," *Wetlands Ecology and Management,* vol. 24, pp. 73-92, 2016/02/01 2016.

[41] I. Nitze, G. Grosse, B. M. Jones, C. D. Arp, M. Ulrich, A. Fedorov, *et al.*, "Landsat-based trend analysis of lake dynamics across northern permafrost regions," *Remote Sensing,* vol. 9, p. 640, 2017.

[42] R. K. Jaiswal, A. K. Lohani, and H. L. Tiwari, "Statistical Analysis for Change Detection and Trend Assessment in Climatological Parameters," *Environmental Processes,* vol. 2, pp. 729-749, 2015/12/01 2015.

[43] X. Song, S. Song, W. Sun, X. Mu, S. Wang, J. Li*, et al.*, "Recent changes in extreme precipitation and drought over the Songhua River Basin, China, during 1960–2013," *Atmospheric Research,* vol. 157, pp. 137-152, 2015.

[44] G. M. Tsidu, "Secular spring rainfall variability at local scale over Ethiopia: trend and associated dynamics," *Theoretical and Applied Climatology,* vol. 130, pp. 91-106, 2017.

[45] R. Manzanas, L. Amekudzi, K. Preko, S. Herrera, and J. M. Gutiérrez, "Precipitation variability and trends in Ghana: An intercomparison of observational and reanalysis products," *Climatic change,* vol. 124, pp. 805-819, 2014.

[46] A. G. Frazier and T. W. Giambelluca, "Spatial trend analysis of Hawaiian rainfall from 1920 to 2012," *International Journal of Climatology,* vol. 37, pp. 2522-2531, 2017.

[47] I. T. Pedron, M. A. Silva Dias, S. de Paula Dias, L. M. Carvalho, and E. D. Freitas, "Trends and variability in extremes of precipitation in Curitiba–Southern Brazil," *International Journal of Climatology,* vol. 37, pp. 1250-1264, 2017.

[48] F. Hallouz, M. Meddi, G. Mahe, H. Karahacane, and S. Ali Rahmani, "Tendance des précipitations et évolution des écoulements dans un cadre de changement climatique: bassin versant de l'oued Mina en Algérie," *Revue des sciences de l'eau / Journal of Water Science,* vol. 32, pp. 83-114, 2019.

[49] D. Bambara, A. Bilgo, H. E., M. D., T. A., and H. V., "Perceptions paysannes des changements climatiques et leurs conséquences socio environnementales à Tougou et Donsin, climats sahélien et sahélo-soudanien du Burkina Faso," *ulletin de la Recherche Agronomique du Bénin (BRAB),* vol. 16, pp. 8-16, 2013.

[50] CINTECH, "Schéma directeur d'aménagement de l'espace du lac Dem," Ouagadougou, Burkina Faso, 72-76 2018.

[51] T. Landmann, M. Schramm, R. R. Colditz, A. Dietz, and S. Dech, "Wide Area Wetland Mapping in Semi-Arid Africa Using 250-Meter MODIS Metrics and Topographic Variables," *Remote Sensing,* vol. 2, pp. 1751-1766, 2010.

[52] E. Riddell, S. Lorentz, and D. Kotze, "The hydrodynamic response of a semi-arid headwater wetland to technical rehabilitation interventions," *Water SA,* vol. 38, pp. 55-66, 2012.

[53] N. O. Uluocha and I. C. Okeke, "Implications of wetlands degradation for water resources management: Lessons from Nigeria," *GeoJournal,* vol. 61, pp. 151-154, 2004/10/01 2004.

[54] E. P. Glenn, R. Felger, A. Burquez, and D. Turner, "Cienega de Santa Clara: endangered wetland in the Colorado River delta, Sonora, Mexico," *Natural resources journal,* vol. 32, pp. 817-824, 01/01 1992.

[55] M. Wang, S. Qi, and X. Zhang, "Wetland loss and degradation in the Yellow River Delta, Shandong Province of China," *Environmental Earth Sciences,* vol. 67, pp. 185-188, 2012/09/01 2012.

[56] D. Mohamed, S. Labar, M. Fethi, and B. Imad-eddine, "Etude des changements écologiques des zones humides en milieu désertique en utilisant l'imagerie LANDSAT et le SIG," *International Journal of Environment and Water,* vol. 2, pp. 81-87, 01/01 2013.

[57] P. Zhu and P. Gong, "Suitability mapping of global wetland areas and validation with remotely sensed data," *Science China Earth Sciences,* vol. 57, pp. 2283-2292, 2014/10/01 2014.

[58] S. HU, Z. NIU, H. ZHANG, Y. CHEN, and N. GONG, "Simulation of spatial distribution of China potential wetland," *Chinese Science Bulletin,* vol. 60, p. 3251, 2015.

[59] R. Tiner, "Wetlands: An Overview," ed, 2015, pp. 3-18.

[60] G. Pinay, C. Gascuel, A. Menesguen, Y. Souchon, M. Le Moal, A. Levain*, et al.*, "L'eutrophisation: manifestations, causes, conséquences et prédictibilité. Synthèse de l'Expertise scientifique collective CNRS - Ifremer - INRA - Irstea.," 2017.

[61] K. Souberou, K. Agbossou, and E. Ogouwale, "Inventaire et caractérisation des bas-fonds dans le bassin versant de l'Oti au Bénin à l'aide des images Landsat et ASTER DEM," *International Journal of Environment, Agriculture and Biotechnology (IJEAB),* vol. 2, pp. 1601–1623, 2017.

[62] S. Tao, J. Fang, X. Zhao, S. Zhao, H. Shen, H. Hu*, et al.*, "Rapid loss of lakes on the Mongolian Plateau," *Proc Natl Acad Sci U S A,* vol. 112, pp. 2281-6, Feb 17 2015.

[63] MEDD, "Plan d'action National pour la gestion durable des Zones Humides du Burkina Faso," 2013.

[64] IPCC, "Africa," in *Climate Change 2014 – Impacts, Adaptation and Vulnerability: Part B: Regional Aspects: Working Group II Contribution to the IPCC Fifth Assessment Report: Volume 2: Regional Aspects*. vol. 2, C. Intergovernmental Panel on Climate, Ed., ed Cambridge: Cambridge University Press, 2014, pp. 1199-1266.

[65] AEN, "Schema directeur d'amenaement et de gestion des eaux de surface de l'agence de l'eau du Nakanbé: Tome 1 Etat des lieux," 2015.

[66] V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir*, et al.*, "Climate change 2014 impacts, adaptation, and vulnerability Part B: regional aspects: working group II contribution to the fifth assessment report of the intergovernmental panel on climate change," in *Climate Change 2014: Impacts, Adaptation and Vulnerability: Part B: Regional Aspects: Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* ed: Cambridge University Press, 2014, pp. 1-1820.

[67] W. Claude, S. Léon, J. Kini, N. Tiatité, S. Mohamed, and S. Valentin, "Vers une gestion intégrée des ressources en eau au Burkina Faso," 2017.

[68] e. H. H. Hussein, C. Laurence, and T. Laurent, "Modélisation de l'érosion hydrique à l'échelle du bassin versant du Mhaydssé. Békaa-Liban," *VertigO - la revue électronique en sciences de l'environnement [En ligne],* vol. 18 2018.

[69] DGRE, "Etat des lieux des ressources en eau du Bassin du Nakanbé," Burkina Faso 2010.

[70] R. Ouedraogo, *Fish and fisheries prospective in arid inland waters of Burkina Faso, West Africa*: na, 2010.

[71] AEN, "Espace de competence de l'agence de l'eau du Nakanbe (EC-AEN): Schema directeur d'amenagement et de gestion de l'eau (SDAGE)," Agence de l'Eau du Nakanbé 2019.

[72] G. Serpantié and P. Zombre, "Contraintes et potentialités des petits bas-fonds soudano-sahéliens vis à vis d'une riziculture sous aménagement d'étalement de crues: expérience du programme R3S à Bidi (Nord Yatenga)," in *Atelier National sur la Riziculture et Commission du Programme Riz*, Bobo Dioulasso, 1994, p. 20 multigr.

[73] A. Mama, B. A. Sinsin, C. D. Cannière, and J. Bogaert, "Anthropisation et dynamique des paysages en zone soudanienne au nord du Bénin," *Tropicultura,* vol. 31, pp. 78-88, 2013.

[74] A. Zare, "Climate variability and natural resource management in a tropical wetland: an integrated approach applied to the case of the inner Niger Delta (Mali) Variabilité climatique et gestion des ressources naturelles dans une zone humide tropicale: une approche intégrée appliquée au cas du delta intérieur du fleuve Niger (Mali)," Université Montpellier Institut international d'ingénierie de l'eau et de l'environnement, 2015.

[75] A. Ilboudo, S. Soulama, E. Hien, and P. Zombre, "Perceptions paysannes de la dégradation des ressources naturelles des bas-fonds en zone soudano-sahélienne: cas du sous bassin versant du Nakanbé-Dem au Burkina Faso," *Int. J. Biol. Chem. Sci.,* vol. 14, pp. 883-895, 2020.

[76] K. H. Thamaga, T. Dube, and C. Shoko, "Advances in satellite remote sensing of the wetland ecosystems in Sub-Saharan Africa," *Geocarto International,* pp. 1-23, 2021.