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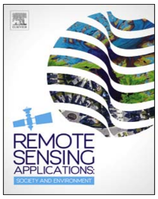

Mapping the spatial distribution of small reservoirs in the White Volta Sub-basin of Ghana

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ABSTRACT

Small reservoirs provide vital ecosystem services in the semi-arid part of Ghana. Their main role is the provisioning of water for irrigation in this water-scare part of the country. They also serve as source of water for fishing, recreation, drinking, and other domestic uses and play crucial roles in evaporation, water productivity, water scarcity mitigation and climate modulation in this area. As such, their accessibility by the populace is vital to their well-being. Also, their locations, surface area and capacity (volume) are required for water resources assessments and hydrological modelling. This work was done to map the distribution of the small reservoirs in the White Volta sub-basin in Ghana. The work assessed the accessibility of artificially built small reservoirs in the relevant communities using satellite images and ground information. The study used six Landsat 8 Operational Land Imager images covering the study area. Histogram thresholding technique was used to delineate the waterbodies from their adjacent uplands. Accuracy assessments were done through field observed data and Google Earth images. The method used produced a positional accuracy of 94%. The study estimated that there are approximately 254 small reservoirs of surface areas between 1 and 53 ha in the sub-basin. The combined surface area and volume of the small reservoirs were estimated to be 1585.265 ha and 21.154×10^6 m^3 respectively. The study estimated only 35% of communities within the sub-basin have access to small reservoirs. The study concluded that cluster of communities and population density are the general determinants of the distribution of small reservoirs in the sub-basin. However, rainfall distribution and suitability of soil for large-scale crop production may also be some important factors dictating the distribution of small reservoirs in the White Volta sub-basin in Ghana.

1. Introduction

The White Volta Basin in Ghana is a semi-arid land in sub-Saharan Africa with highly variable climate (Mul et al., 2015). The area experiences a unimodal rainfall pattern with the rainy season starting from April/May to September/October and dry season beginning November and ending in March (Gyau-Boakye and Dapaah-Siakwan, 1999). Most of the inhabitants of the area are farmers who cultivate crops and rear farm animals (Ofosu et al., 2010) and as such heavily depends on water for their livelihood. However, apart from the fact that the rainfall pattern does not supports all year water access, climatic changes has coupled the uncertainties associated with access to water for both domestic and agricultural use. As such, the development of irrigation schemes is the only way farmers can cultivate in the dry season and during the dry spells in the rainy season.

To overcome water scarcity alongside creating new income sources for the steadily growing populations of the sub-basin, hundreds of small-multi-purpose reservoirs were built in the colonial era up to the 1960s (Venot, 2011). The priority of the development agenda in the basin-wide scale during the 1970s and 1980s shifted towards medium and large scale dams with little attention to small reservoirs (Venot et al., 2011). The growing disenchantment with the costs involved and the social and environmental consequences of large-scale multi-purpose dams (WCD, 2000) led to a renewed interest by donors in small reservoirs development in the 1990s (McCully and Pottinger, 2009; Douxchamps et al., 2012), after the droughts of the 1980s which lead to water scarcity, food shortages and hunger (Leemhuis et al., 2009). Small reservoirs have since become a way to develop small-scale irrigation (Venot and Krishnan, 2011), especially in areas prone to problems with rainfall. They allow mitigation of negative impact of inter-

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annual flooding, supply of water for livestock, domestic and irrigation purposes (Jean-françois et al., 2015). Apart from the above mentioned usage, it also provides water for fishing and construction of buildings, roads, etc. (Sally et al., 2011).

In the White Volta Sub-basin in Ghana, mapping of small reservoirs using satellite images has mainly been done for the Upper East Region. Although most of these studies used data from different satellite sensors and different images classification algorithms to delineate the water-bodies, the studies has been successful in providing statistics on the distribution, status and storage capacity of the small reservoirs in the region. Liebe et al. (2005) used Landsat images to map the distributions and surface area of small reservoirs in the Upper East of Ghana. The study provided quantitative values for the number and surface area of small reservoirs within the region. The study then used bathymetric survey of some of the reservoirs to derive a relation for estimating the volume of the reservoirs as a function of the satellite derived surface area. Liebe et al. (2008), Annor et al. (2009); Eilander et al. (2014) all used images from active sensors to map the distribution of small reservoirs in the Upper East Region of Ghana. Although each of the three study applied different image classification algorithm to the radar images used, the studies proved that radar images could also be used to delineate small reservoirs from their adjacent uplands with high accuracy. Ofosu et al. (2014) also employed satellite images to map the distribution of small reservoirs in the Volta Basin.

However due to demographic differences, size and scale of agricultural production as well as environmental and financial demands, building of small reservoirs within the White Volta Sub-basin has not been well organized, and the collective number, size and capacity of some are not known. Poor maintenance culture and high run-offs in areas where these reservoirs are located has given way for the invasion of weeds (Annor et al., 2009) and sediments which often results in siltation and eventual dysfunctioning of some of the reservoirs (Andreini et al., 2009). High abstraction of water from these reservoirs as well as the extreme and prolonged drought events that characterize the recent climatic conditions of the sub-basin (McCartney et al., 2012) has also caused some of the reservoirs to dry-up and are hence no more in-use. These challenges affect the spatiotemporal distribution of the small reservoirs both temporarily and permanently. There is thus the need to map and update the statistics of these reservoirs to identify the current collective number, size and capacity of these reservoirs for water resources assessment of the sub-basin. Also, none of the small reservoirs mapping studies so far conducted has reported on the accessibility of these small reservoirs to the communities within which they are found. This creates a knowledge gap in the per capita water accessibility assessment within the sub-basin. It is therefore prudent to assess the accessibility of small reservoirs within the sub-basin in spatial context. Moreover, with Ghana government's short-term policy of providing a water-supply dam for each community in the north of the country, long-term policy of creating a national spatial data infrastructure as well as her goal of producing 'sustainable data for sustainable development' (United Nations, 2015) as required by the international community, there are ample reasons to assess the accessibility of small reservoirs to the populace within this water-scarce area. This study was therefore conducted to provide statistics and ready data on the distribution and accessibility of small reservoirs to communities in the White Volta sub-basin in Ghana using Landsat 8 satellite images and field data.

2. Methodology and materials

2.1. Study area

The area under this study is the part of the White Volta Sub-Basin within Ghana (Fig. 1(a),). This area spans through three regions in the north of the country namely; Northern Region, Upper West Region and Upper East Region. It is located between latitudes 8⁰42' N and 11⁰01' N and longitudes 0⁰13' E and 2⁰30' W. The sub-basin covers a land area of about 49,583 km^2 with all the river systems draining into the White Volta River (Fig. 1(b)). The terrain is generally flat with few highlands.

The climate of the area is variable, both spatially and temporally with climatic zones spanning from Guinean Savanna Zone, Sudanian Savanna Zone and a small portion of Sudano-Sahelan Zone (Kranjac-Berisavljevic et al., 1999). Annual rainfall in the Guinean Zone is between 1000 and 1300 mm whiles the Sudano-Sahelian Zone and the Sudanian Zone receives annual rainfall between 500 and 900 mm and between 900 and 1100 mm respectively (Kranjac-Berisavljevic et al., 1999) (Fig. 1(c)). About 70% of the annual rainfall in the area occurs during the months of July, August and September, with little or no rainfall between November and March. Rainfall is often erratic with considerable variations between successive seasons, with regard to the time of onset, duration and amount (Obuobie, 2008). The rainy season is also characterized by dry spells of varying duration (Kadyampakeni et al., 2017).

2.2. Data used

2.2.1. Field data

Field observed data used in this study include flood inundation extent and coordinates of water-land transition points around some selected small reservoirs distributed within the study area. A handheld GPS and a digital camera were used to record these features during a field visit to the study area in October 2016. The handheld GPS was also used to measure the distance of each selected small reservoir to the community/communities it serves. Each measurement was done by tracking the approximate linear distance between the embankment of the reservoir and a location within the community. This location is usually the second or third building of the community from the reservoir. Community members' knowledge and participation in defining this distance was greatly utilized.

Various ancillary data were also used. These included vector dataset of topographical map of Ghana with layers including contours, roads, rivers and administrative boundaries of the country, projected onto the UTM Zone 30 N coordinates system. This dataset was obtained from the Survey and Mapping Division of the Ghana Lands Commission. Vectors datasets of the agro-ecological zones and climatic zones were obtained from the Savanna Accelerated Development Authority (SADA) website (http://www.sadagh.org/) and the dataset were already projected onto the UTM Zone 30 N coordinate system. Boundary shapefile of Africa countries was also obtained from the Thematic Mapping API website (http://thematicmapping.org/api/). Though this layer had the WGS 84 coordinate system as its reference, no attempt to project the data onto the UTM Zone 30 N coordinate system was made as that will distort the data. However, this data was successfully used in depicting the study location in relation to neighboring countries (Fig. 1(a)). These ancillary datasets provided information about the location, climate, agro-ecology and rivers systems the study area.

A flowchart of the methodology used in this study is shown in Fig. 2.

2.2.2. Satellite images

Six Landsat 8 images covering the study area were downloaded from the USGS website Global Visualization Viewer (http://glovis.usgs.gov/). These images were acquired in October and November 2016. This interval is the period Leibe et al. (2005) showed that the reservoirs were likely to be fully filled with water and hence the satellite images captures the full surface area of the reservoirs, which can give a good estimation of the surface area of the reservoirs. The characteristics of these images are summarized in Table 1.

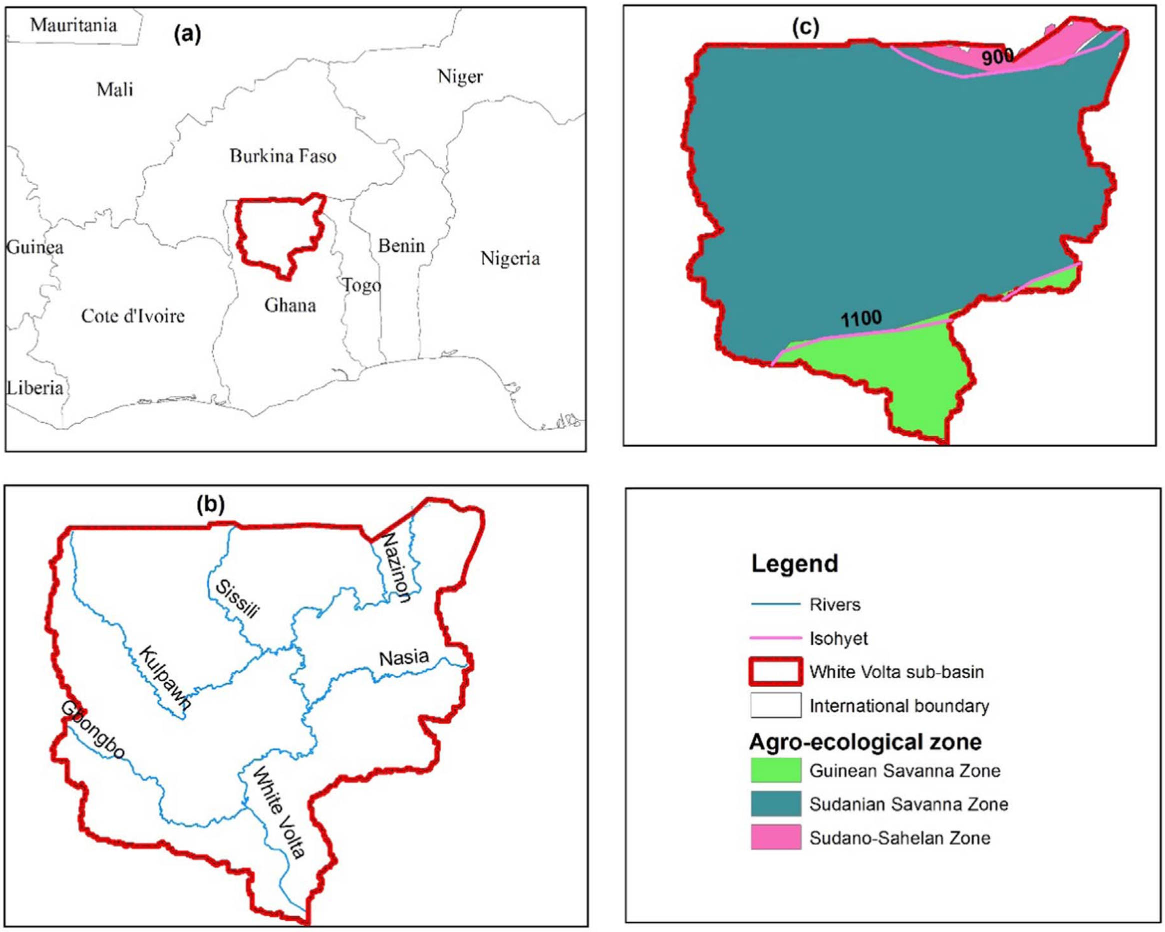


Fig. 1. Study area: (a) Geographic location (b) River systems (c) Isohyets and agro-ecological zones of the White Volta Sub-basin in Ghana.

2.3. Image pre-processing

Both ESRI ArcGIS and Erdas Imagine were used to pre-process the images. Landsat 8 OLI Level 1 T products have been geometrically corrected using ground control points and digital terrain model corrections (Storey et al., 2014; DI/USGS, 2016). This has practically proven images from OLI to be geometrically accurate (Storey et al., 2014). As such, no further geometric correction were done for the images used in this study.

Radiometric corrections were done by converting all the DN values of each image band into top-of-atmosphere planetary reflectance with a correction factor of the sun angle using Eqs. (1) and (2) below

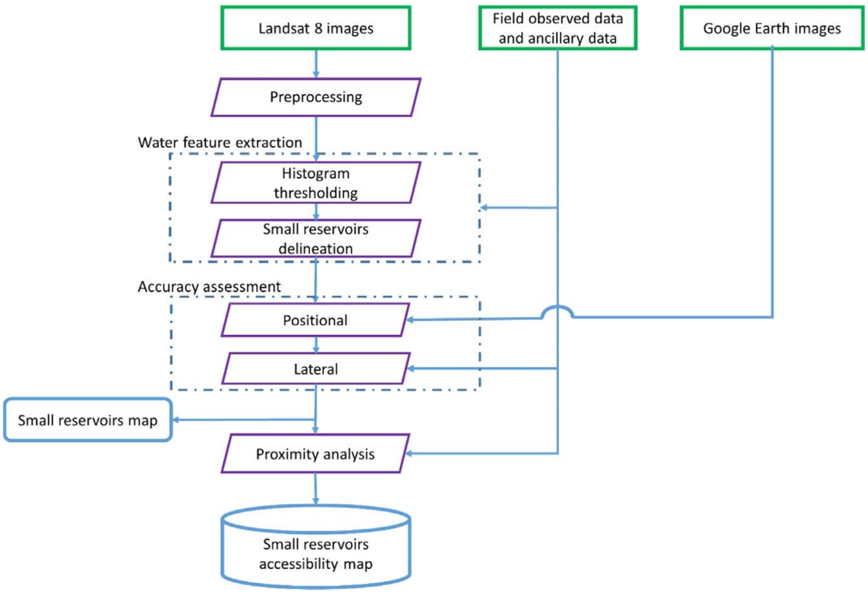


Fig. 2. Flowchart of the methodology.

Table 1
Characteristics of Landsat 8 data used.

Sensor	Path	Row	Date
Landsat 8	194	52	28-10-2016
Landsat 8	194	53	28-10-2016
Landsat 8	194	54	28-10-2016
Landsat 8	195	52	20-11-2016
Landsat 8	195	53	20-11-2016
Landsat 8	195	54	20-11-2016

respectively (Landsat, U.S.G.S., 2016):

$$\rho\lambda' = M\rho * Qcal + A\rho \tag{1}$$

$$\rho\lambda = \rho\lambda' / \cos(\theta) \tag{2}$$

where:

$\rho\lambda'$ = Top of Atmosphere Planetary Reflectance

$M\rho$ = Band Specific Reflectance Multiplicative Scaling Factor for the Band

$Qcal$ = DN Values

$A\rho$ = Band Specific Reflectance Additive Scaling Factor for the Band

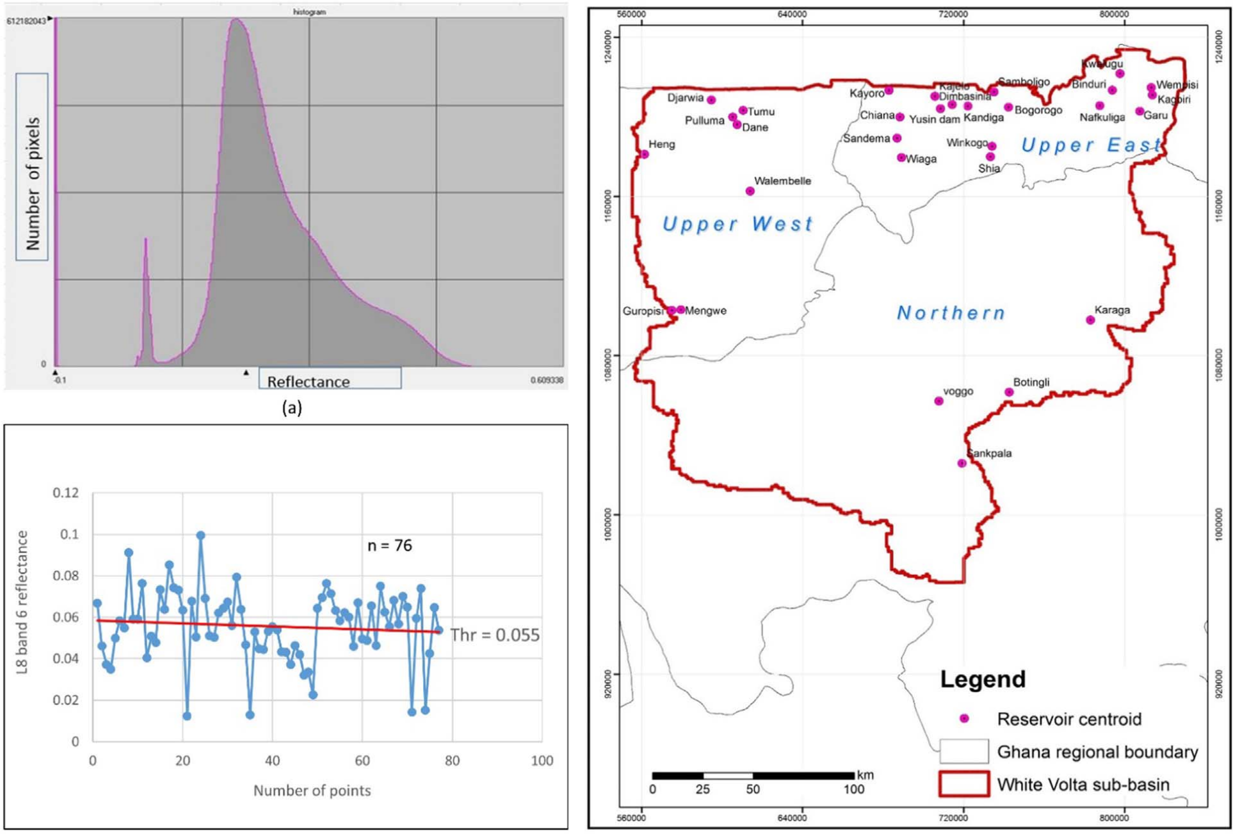
$\rho\lambda$ = Correction Factor for Sun Angle

$\cos(\theta)$ = Cosine of Local Sun Elevation Angle

The bands were then stacked, mosaicked and clipped to the boundary of the sub-basin to obtain a complete coverage of the study area. Though only the band 6 was used as the input data for the histogram thresholding (Section 2.4.1), the inclusion of the other bands aided the visual identification and interpretation of other features such as buildings, large waterbodies and uplands features of the small reservoirs.

2.4. Water feature extraction

Mapping of waterbodies from conventional land surveying is a tedious task and at times inaccessibility becomes a hindrance. However, space-borne satellite systems observe the earth surface in entire field of view of sensors and records ground objects (Duong, 2012). Extraction of waterbodies from satellite images of varying spatial, temporal and spectral resolutions have been widely explored by researchers to obtain and analyze geo-information (Jawak et al., 2015). The technique of remote sensing involves the measuring of reflected radiance from an object that is captured and this depends on the extent of electromagnetic radiation absorbed by the object; that is, the more it absorbs, the less it reflect (Mishra and Prasad, 2015). Optical satellite systems are most frequently used in water body extraction research. The parts of the electromagnetic spectrum covered by these sensors include the Visible and Near- Infrared VNIR ranging from 0.4 to 1.3 µm, the Shortwave Infrared SWIR between 1.3 and 3.0 µm, the Thermal Infrared TIR from 3.0 to 15.0 µm and the Long-Wavelength Infrared LWIR from (7–14 µm). A review of these sensors can be found in Nath and Deb (2010). Various techniques and algorithms such as supervised and unsupervised classification, feature extraction, and data fusion have been adopted by researchers to extract water features from satellite imagery (e.g. Mcfeeters, 1996; Frazier and Page, 2000; Ji et al., 2009; Du et al., 2014; Ouma and Tateishi, 2006; Bhardwaj et al., 2015; Jiang and Wang, 2016) with each method has its own merits and demerits (Duong, 2012). The use of water indices and histogram thresholding, which form part of feature extraction techniques (Duong, 2012), have taken the center stage in waterbody extraction due to their simplicity



(a) (c) (b)

Fig. 3. (a) Histogram of the mosaicked L8 band 6 image retrieved from Erdas Imagine (b) Spread of the selected small reservoirs used for the histogram thresholding and the proximity analysis (c) Scatter plot of the reflectance from the 76 water-land transition points around the selected reservoirs.

and the accuracy they give. A detailed review of algorithms for extraction of water bodies from satellite image can be found in Jawak et al. (2015) and Jiang et al. (2014). Histogram thresholding techniques was used in extracting water features in this study.

2.4.1. *Thresholding on SWIR*

The thresholding technique involves two parts; decomposition of the image into sub images according to spectral reflectance patterns and level slicing into water and land using different threshold values for the SWIR band (Duong, 2012). For this research work, it was done in Erdas Imagine where the Modular Tool was used to obtain a water only layer. Deka et al. (2011) has shown that this method is effective and has been used in many studies to delineate water bodies from their surrounding uplands. The method results in precise grouping, for example, water pixels from land pixels from which a binary layer containing water-only can be created as it was done in Ghansah et al. (2016).

Histogram thresholding technique was executed on the Shortwave Infrared (SWIR) band 6 of the mosaicked images. The resultant histogram displayed a double peak curve of water and land reflectance. Between these double peaks lies the transition point (threshold pixel) of water and land, Fig. 3(a). Though accurate determination of this value can be a confusing because of reflection from mixed water-land features, precise selection of this threshold value is possible and is essential for obtaining a good classification. To avoid the confusion this represents, the inundation extents of 30 small reservoirs spatially distributed within the study area (Fig. 3(b)) were marked with a handheld GPS just after the peak flooding season in early October 2016. The decision to select these reservoirs were based on authors' knowledge of these reservoirs and their accessibility. As such, coordinates of water pixels at transition points between water and land around the 30 selected small reservoirs within the study area were selected. This took the form of recording the GPS coordinates of the sample points (76 in total), which were then superimposed onto the mosaicked band 6 satellite images to extract their corresponding reflectance values. A scatter plot of the distribution of the reflectance was done and a mean was then computed to obtain a precise reflectance threshold value (Thr) for slicing the image, (see Fig. 3(c)).

2.5. *Reservoirs delineation*

The binary image created was processed to exclude water pixels from all other pixels leaving a water only layer. Small reservoirs were separated from other categories of water bodies. Considering the 30 m spatial resolution of the Landsat images used, the probability of inaccurately identifying smaller features is higher (Leibe et al., 2005). Leibe et al. (2005) defined small reservoirs to have a surface area between 1 and 100 ha based on the 30 m moderate resolution of Landsat ETM images. Likewise, due to the 30 m moderate resolution of the Landsat 8 images used, this study regarded small reservoirs to have surface area between 1 and 100 ha inclusive. As such all waterbodies outside this range were deleted from the layer. Though natural reservoirs (ponds) are used for fishing activities in this area, they are not known to be used for irrigational purposes (Mul et al., 2018) and were therefore considered to be of limited importance to the overall purpose of this water accessibility study. Moreover, majority of these ponds completely dries out during the dry season and ceased to be of benefit in terms of water accessibility. As such, all reservoirs within the floodplain of the major river systems in the sub-basin were deleted from the layer. This was achieved by masking off all waterbodies within the floodplains of the major rivers by superimposing a flood inundation layer (developed using Height Above Nearest Drainage (HAND) contours (Nobre et al., 2016)) of the White Volta River on the small reservoirs layer generated. This step was necessary to ensure that almost all natural reservoirs (ponds) has been removed and the small reservoirs layer obtained contains only artificially built infrastructures.

2.6. *Accuracy assessment*

In assessing the accuracy of the delineated small reservoirs, both positional and lateral accuracies were assessed. Positional accuracy defines the quantitative value that indicates the positional difference between two geospatial layers or between a geospatial layer and geographical reality (ArcGIS Desktop, 2017a, 2017b) whiles lateral accuracy defines the quantitative value that represent the lateral differences between two geospatial layers or between a geospatial layer and geographical reality. In the positional accuracy assessment, the center coordinates of 100 delineated small reservoirs were projected onto Google Earth image captured in 2016. These 100 coordinates included the known coordinates of the 30 small reservoirs that were visited during the field survey. Manual inspection was done by visually counting the number of projected centroids that fell on designated reservoirs on the Google Earth. The total number of matching coordinates points were then counted to give the positional accuracy.

Lateral accuracy assessment was done by comparing the surface area of 30 of the delineated reservoirs to the measured surface area of the corresponding 30 small reservoirs recorded using the handheld GPS during the field survey. A *t*-test computation was then done to find the differences between the two sets of values.

2.7. *Spatial distribution of the reservoirs*

The coordinates and surface areas of the small reservoirs were computed in ArcGIS environment. To estimate the volume of the reservoirs, an existing regional area-volume relation that has been developed in previous studies for the area were considered. Leibe et al. (2005) and Annor et al. (2009) independently developed equations that relate the area of small reservoirs to their volume in the UER of Ghana. Their studies used bathymetric measurements of some small reservoirs to relate the surface area obtained from satellite images to the volume. As the region is 'geomorphologically' (Annor et al., 2009) identical, they were able to develop precise relations between the surface area and volume with goodness of fit above 95% in both studies. The equations are (3) and (4) from Leibe et al. (2005) and Annor et al. (2009) respectively.

$$Volume = 0.00857{*}Area^{1.4346}\,(\mathrm{m}^3) \tag{3}$$

$$Volume = 0.00857{*}Area^{1.44}\,(\mathrm{m}^3) \tag{4}$$

Where:

> *Volume* is the volume of the reservoir measured in cubic meter and *Area* is the surface area of the reservoir measured in squared meter

Thus, both studies produced very similar area to volume relations for the region. As Leibe et al. (2005) used Landsat images as well as similarity in the geomorphology between the Upper East Region and the sub-basin, the relation established by Leibe et al. (2005), was used to compute the volume of the small reservoirs delineated in this study.

2.8. *Proximity of reservoir to communities*

As one of the primary objectives, this study assessed which communities within the study area have access to small reservoirs. To do this assessment, a proximity analysis was performed in ESRI ArcGIS using the Generate Near Table tool. Based on Dijkstra's algorithm to find the shortest path between an input feature P, and a near feature S, this tool computes the shortest distance $\boldsymbol{L}$, angle (θ^0), coordinates $(X_P,\,Y_P) and (X_s Y_s)$ and other proximity information between the two closest features. In cases where there are multiple points (as in this study) in both the input feature and the near feature, the tool computes the distances between all the points and selects the shortest distances and other proximity information between each closest input feature.

This tool then writes the results to a new table (ArcGIS Desktop, 2017a, 2017b).

Sample point features of 720 communities (240 communities from each region) obtained from the national database and from the field survey was used as the input feature. The small reservoirs layer delineated in this study was then used as the near feature. It was observed from the fieldwork that almost all the small reservoirs surveyed were sited within 2 km of the community/communities they serve. It was therefore assumed that any community/communities without a reservoir within a 2 km radius is deemed not to have access to a small reservoir. As such, a 2 km distance was specified for the proximity analysis.

3. Results

3.1. Waterbodies extraction

The thresholding technique was successful in extracting the small reservoirs from their adjacent uplands. By acquiring training samples from the field to define the spectral threshold value between the land and waterbodies, precision of the thresholding technique was obtained. A reflectance threshold value of 0.055 was obtained in this study and was thus used to delineate the water from the adjacent surrounding. All reflectance values between −0.100 and 0.055 inclusive were deemed to be water and values between 0.056 and 0.609 (Fig. 3(b), Section 2.4.1) were deemed to be adjacent uplands of the waterbodies.

3.2. Small reservoirs in the white volta sub-basin

The results obtained from this study indicated that there are an estimated 254 small reservoirs in the White Volta sub-basin in Ghana. These are man-made dams with surface areas ranging between 1 and 54 ha (Fig. 4) and with storage capacity between 4.780 × 10^3 and 1.398 × 10^6 m^3 (Table 2).

In a comparison of the results obtained in this study and Leibe et al. (2005), Leibe et al. (2005) obtained 154 small reservoirs in the UER whiles this study obtained 171 small reservoirs in the UER. The difference in the number of small reservoirs in this region indicate an increase of 17 small reservoirs in-between the dates of acquisition of the satellites images used in these studies (1999/2000 and 2016).

Table 2
Composition and distribution of the small reservoirs.

	Area (ha)	Volume (m^3)	Total number
Northern	298.540	4963761.825	51
UE	1077.864	14693963.71	171
UW	208.861	2885254.95	32
Total	1585.265	22542980.49	254

3.3. Accuracy assessments

Out of the 100 coordinates that were projected onto the Google Earth, 94 of them fell on reservoirs. Of the 30 coordinates points which were known earlier through the ground survey, all the coordinates fell exactly on the designated reservoirs. As such, an accuracy of 94% was obtained for the positional accuracy assessment. This provided a reliability of the classification methods used (Fig. 5).

The lateral accuracy assessment indicated that the classification procedure used in this study marginally underestimated and overestimated the surface areas. The maximum difference was 1.909 and the minimum was 0.165 ha, respectively. A t-test of the observed surface areas and delineated surface areas returned a value of 0.317, indicating the similarity between the two sets of values, (Table 3). Considering the differences in field observation dates and image acquisition dates, the estimation was deemed precise.

3.4. Communities access to small reservoirs

The proximity analysis estimated that only 255 out of the 720 communities has access to a small reservoir (Fig. 6). The analysis also showed that one reservoir might serve more than one community Table 4

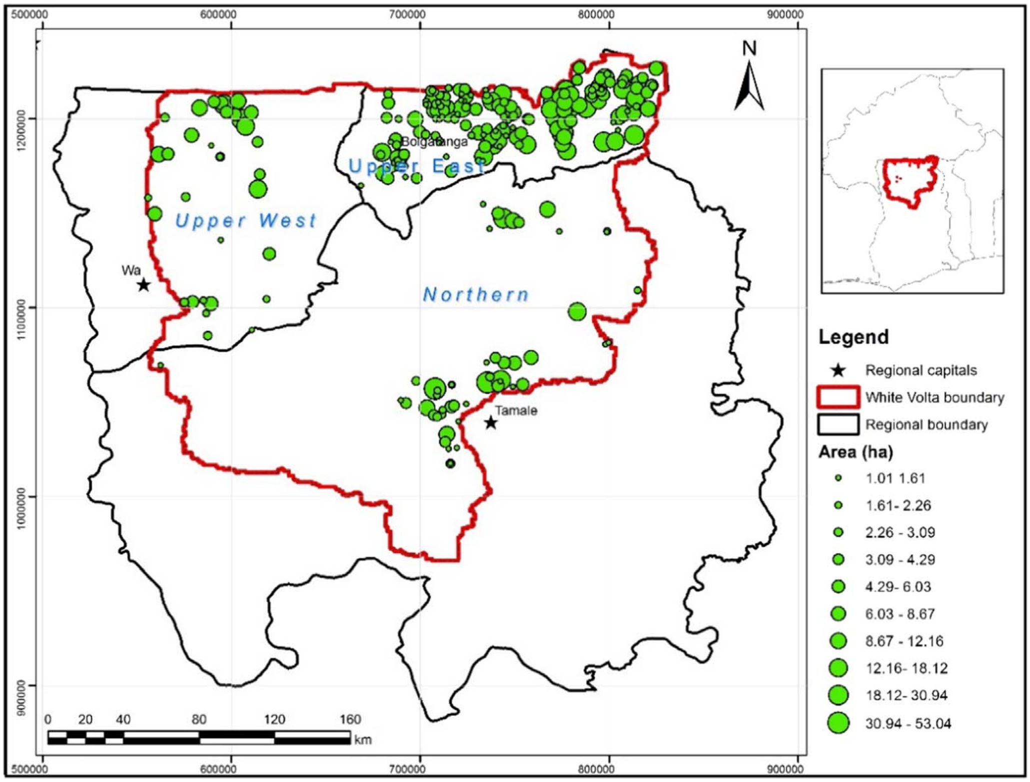


Fig. 4. Distribution of small reservoirs by surface area.

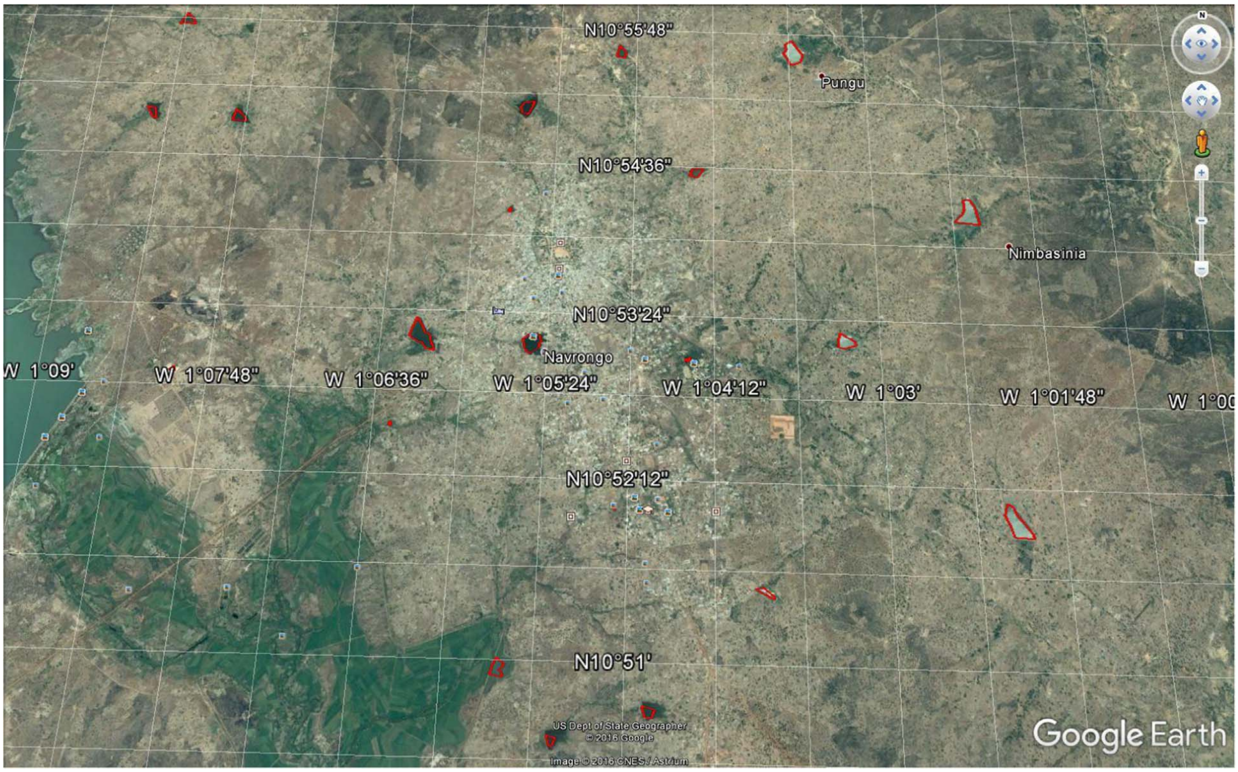


Fig. 5. Delineated small reservoirs superimposed on a Google Earth image.

Table 3
Measured and delineated small reservoirs.

	Name of reservoir	Measured Area (ha)	Delineated Area (ha)	Estimated volume (m^3)
1	Binduri	16.231	16.958	272296.3
2	Bogorogo	5.132	3.878	32794.24
3	Botingli	22.124	23.482	434347.5
4	Chiana	3.152	2.144	14013.8
5	Dane	12.810	13.952	205814.7
6	Dimbasinia	8.093	9.024	110153
7	Djarwia	8.044	9.303	115071.4
8	Garu	10.697	11.682	159529.5
9	Guropisi	2.791	4.515	40789.92
10	Heng	9.172	9.007	109855.4
11	Kagbiri	18.633	19.001	320563.1
12	Kajelo	7.594	6.040	61923.63
13	Kandiga	15.562	16.381	259103.7
14	Karaga	13.512	14.220	211509.8
15	Kayoro	3.241	2.513	17599.36
16	Kwalugu	16.063	15.689	243546.4
17	Mengwe	6.223	4.831	44946.96
18	Nafkuliga	22.023	22.426	406601.9
19	Pulluma	30.941	31.490	661697.2
20	Samboligo	2.626	1.638	9524.354
21	Sandema	6.186	4.996	47165.51
22	Sankpala	2.678	1.082	5253.918
23	Shia	12.982	13.722	200964.7
24	Tumu	7.391	6.430	67739.23
25	voggo	40.243	42.152	1005414
26	Walembelle	12.937	13.489	196087.4
27	Wempisi	13.936	15.171	232093.9
28	Wiaga	9.825	9.366	116191
29	Winkogo	5.142	6.560	69712.57
30	Yusin dam	4.435	5.229	50352.87

4. Discussion

The results point out some general determinants of distribution of small reservoirs in the sub-basin namely: clusters of communities and high human and livestock population centers. Fig. 6 indicates that areas around Bolgatanga, Navrongo, Bawku and Tamale, which are the capitals towns of the Bolgatanga municipality, Kassena-Nankana East municipality, Bawku municipality and the Tamale metropolitan respectively, have high clusters of small reservoirs. These municipalities and metropolitan areas are the most populous administrative areas within the sub-basin (Ghana Statistical Service (GSS), 2012) and their population has been increasing since the 1960s (Ghana Statistical Service (GSS (2013)). They also have high number of peri-urban settlements (Ghana Statistical Service (GSS (2013)) and thus are high population density areas. MOFA Ministry of Food and Agriculture (2004) indicated that large and commercial livestock keepers are predominantly located in urban- and peri-urban areas. Blench (2006) reported that small reservoirs had been traditionally constructed to trap water to serve the growing needs of both humans and livestock, though irrigational purposes has taken over this lead services. Thus, the demand for water for urban and peri-urban agriculture, livestock watering, as well as domestic use, has been the main driver for the construction of small reservoirs within the sub-basin. This accounts for the presence of high number of small reservoirs within areas where the population density is high and where there is cluster of communities. Also, the increase in the number of small reservoirs in the UER between the years 1999/2000 and 2016 (Section 3.2) and population statistics from the GSS indicates that increasing human population correlates with increasing number of small reservoirs, which thus collaborates with the above discussion.

The results also show that though the UER is the smallest (in land size) among the three Northern Regions, it is home to most of the reservoirs within the sub-basin. The region is home to 67% of the total number of reservoirs in the three regions. The high number of reservoirs in this region can be attributed to the low amount of rainfall

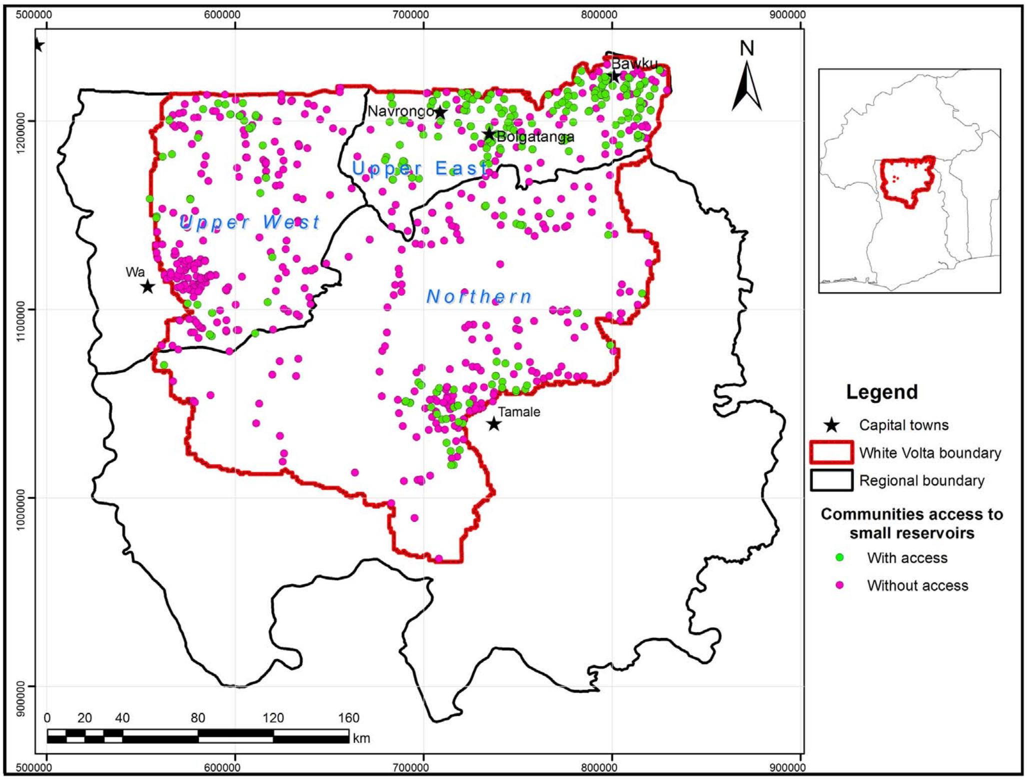


Fig. 6. Communities with and without access to small reservoir.

Table 4
Statistics of the accessibility of small reservoirs by communities.

	Communities with access to small reservoirs		Communities without access to small reservoirs		Total number of communities
	Number	%	Number	%	
Northern	56	21.96	184	39.57	240
UE	162	63.53	78	16.77	240
UW	37	14.51	203	43.66	240
Total	255	100	465	100	720

received in the region as compared to the other two regions (Obuobie et al., 2017; Obuobie et al., 2018), encouraging the building of more reservoirs to sustain life in that region. Fig. 4 reveals that, the north-eastern part of the region has larger reservoirs compared to the western side. This is mainly due to water demand for the large-scale cultivation of onions in this part of the region. The occurrence and suitability of the soil (Lixisols) in the northeastern part of the region for the cultivation of onions (Sinnadurai and Abu, 1977), which is a highly economic commodity, is higher than the other parts of the region and even the other two regions.

The NR is the biggest region (in land size) in the sub-basin. The UWR is the second largest. However, the NR and UWR has only 20% and 13% respectively of the total number of the reservoirs in the sub-basin. This is explained by the reasons that rainfall amount received in these regions is higher than the UER (Obuobie et al., 2017; Obuobie et al., 2018), and hence they are less water-stressed than the UER. The NR in particular, is the confluence of the two main rivers in the northern part of Ghana, the White Volta River and the Black Volta River. Majority of the tributaries of these main rivers (Fig. 1(c), Section 2.1) are also found within this region (McCartney et al., 2012). Farmers therefore tie their water needs more to these rivers systems than to small reservoirs. This reduces their dependence on small reservoirs for agricultural activities making the use of reservoirs not highly patronize as compared to the UER.

5. Conclusion

This work mapped the distribution and assessed the accessibility of artificially built small reservoirs in communities within the White Volta Basin in Ghana. Data used for the study included six Landsat 8 OLI images covering the study area, ground information obtained through field surveys of the area and ancillary data obtained from national departments and online sources. Histogram thresholding technique was applied on the images to delineate the waterbodies from their adjacent uplands. Accuracy assessments were done through field observed data and Google Earth images. The method used produced a positional accuracy of 94% and a t-test value of 0.317 was obtained for lateral accuracy. The study estimated that there are approximately 254 small reservoirs of surface areas between 1 and 53 ha in the sub-basin. Of the total number of reservoirs, 67% are located in the UER whiles the remaining 20% and 13% are located in the NR and UWR respectively. The combined surface area and volume of the small reservoirs were estimated to be 1585.265 ha and $21.154 \times 10^6\ \mathrm{m}^3$ respectively. The study estimated that only 35% of communities within the sub-basin have access to small reservoirs. Conclusions were drawn to the finding that cluster of communities and human and livestock population density are the general determinants of the distribution of small reservoirs in the sub-basin. However, rainfall distribution and suitability of soil for large-scale crop production may also be some important factors dictating the distribution of small reservoirs in the White Volta sub-basin in Ghana. Areas for potential siting of small reservoirs includes the southwestern part of the UWR and the Western half of NR where there are cluster of communities but depleted of reservoirs.

However, the 30 m moderate resolution of the Landsat 8 images used were not deemed high enough to map reservoirs with surface areas less than 1 ha. Higher resolution satellite images are therefore needed to map smaller waterbodies. Integrated with crowdsourcing data, high resolution images can also help to map out more communities especially those in remote areas. There is also a need to develop a standardized hierarchical classification system for communities based on population in order to differentiate between cities, towns, villages and other settlements. This is because this study classified a settlement of about 10 building and a town of thousands of buildings as a community each in the proximity analysis, due to their distinct names and boundary.

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