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Effect of sand mining on riparian landcover transformation in Dallung-Kukou catchment of the White Volta basin, Ghana

Latif Iddrisu Nasare [a,*], Stephanie Asabea Opoku [b], Amos Amponsah [c], Damian Tom-Dery [d], William J. Asante [a], Bernard N. Baatuuwie [c]

[a] Department of Environment and Sustainability Sciences, Faculty of Natural Resources and Environment, University for Development Studies, P.O. Box TL 1882, Tamale, Ghana
[b] Department of Forestry and Forest Resources Management, Faculty of Natural Resources and Environment, University for Development Studies, P. O. Box TL 1882, Tamale, Ghana
[c] Department of Natural Resources and Geo-Information Sciences, Faculty of Natural Resources and Environment, University for Development Studies, P. O. Box TL 1882, Tamale, Ghana
[d] Department of Biological Sciences, Faculty of Biosciences, University for Development Studies, P. O. Box TL 1882, Tamale, Ghana

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ABSTRACT

Rapid urbanization has increased demand for sand in the construction industry to meet housing and infrastructure needs of urban population. The Dallung-Kukuo catchment of the White Volta River Basin is a major sand mining site for the construction industry in Tamale and other peri-urban communities. On the contrary, the river serves as a major source of water supply to the population. Riparian vegetation is essential to water protection, but research has focused extensively on the impact of sand mining on water quality in the river basin. The present study employed GIS and remote sensing techniques coupled with in-situ vegetation sampling to assess riparian land cover changes from 1990 to 2021. Land cover images of the catchment revealed a 14.9% increase in sand mining area, while river bed area and woodland cover decreased by 0.7% and 20%, respectively, from 1990 to 2021. A comparison of woody plant diversity also showed a higher Shannon diversity index in the unmined area of the riparian zone (3.0) compared to the sand mining area (2.0). Environmental Protection Agency and traditional authorities should intensify monitoring to protect the White Volta basin from unsustainable exploitation.

1. Introduction

The world's urban population is growing rapidly with, 90% of urban population growth occurring in Africa and Asia [1]. This rapid urbanization has necessitated expansion of the construction industry to meet housing and infrastructural needs of cities. Sand is a primary raw material for construction and the second most used resource after water [2]. Globally, an estimated 47 to 59 million tons of sand is mined annually for construction [3]. Aside the infrastructural drive for sand mining, the industry provides both direct and indirect employment opportunities [4].

Notwithstanding the socio-economic importance of sand mining, there are accompanying environmental impacts [5]. Riverbeds and coastlines are the most preferred sites for sand mining [6], and the extent of exploitation far outweighs the rate at which sand is

* Corresponding author.
E-mail address: Latifnasare@uds.edu.gh (L.I. Nasare).

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replenished [3]. Sand itself is an integral component of the river bed but excessive exploitation alters the river banks resulting in the diversion of water course [7]. Loosening of soil, also exposes the river to sedimentation [8]. Moreso the process of sand mining entails the creation of access roads to enable haulage of sand [9], which results in the loss of riparian vegetation in the river basin [4].

Riparian zone is the space between the stream's edge and the organic-mineral soil border [10]. Plants growing at the water edge along the banks constitute the riparian vegetation [11]. Riparian zones are therefore transition zones that regulate ecological processes in both terrestrial and aquatic ecosystems, allowing animals to travel between these ecosystems [12]. They also serve as places where overland and subterranean flow pathways connect rivers and upland run-off [13]. The vegetation protects river banks from erosion, reduces evaporation, and filters soil sediments and nutrients from run-off [14,15]. Owing to the relevance of riparian vegetation in the protection of rivers, most Forest Reserves in Ghana are located around river catchments, and primarily gazetted for water protection [16,17].

The Dallung-Kukou catchment of the Nawuni sub-basin is a source of water supply to Tamale and other peri-urban towns of the northern region. Ironically, the catchment is also a sand mining site for the construction industry. Sand mining is exacerbated by rapid expansion of housing and other infrastructure in response to urbanization in northern Ghana. Sand mining in Dallung-Kukou poses a threat to water supply hence the need to examine the impact of sand mining on the river basin. Although, there are existing studies [13, 18] on the subject, these have all been skewed towards water quality without examining the effect of mining on riparian land cover.

Understanding the riparian landcover change would be essential to policy development for protection of the river basin. These changes can be detected through the classification of remotely sensed data [19]. GIS and remote sensing techniques have the capacity to detect change specific to a geographical location and therefore serve as an efficient tool for land cover change detection [20]. This information would be relevant in projecting future land cover scenarios of the river catchment. Therefore, the present study investigated land cover change and woody plant diversity in the riparian zone of Dallung-Kukuo catchment.

2. Materials and methods

2.1. Study area

The White Volta Basin (WVB) covers a land area of 106, 000 km^2 which constitutes an estimated 28% of the entire Volta Basin. Sissili, Nazinon, and Nawuni rivers are known to be the main tributaries of the WVB [21]. Dalung Kukou catchment is within the Nawuni Sub Basin of the WVB which serves as a major sand mine for the construction industry in the northern region of Ghana. The catchment lies between latitude 9° 39' and 9° 41' N of the equator and longitudes 1° 0' and 1° 2' W of the Greenwich meridian (Fig. 1).

The climate of the area is marked by the wet and dry seasons of the Guinea savanna agroecological zone. The dry season spans from October to June and is characterised by dry harmattan winds blowing from the Sahara. The wet season on the other hand spans from May to September recording a mean annual precipitation of 900–1100 mm. The Dallung-Kukuo catchment has a relatively low

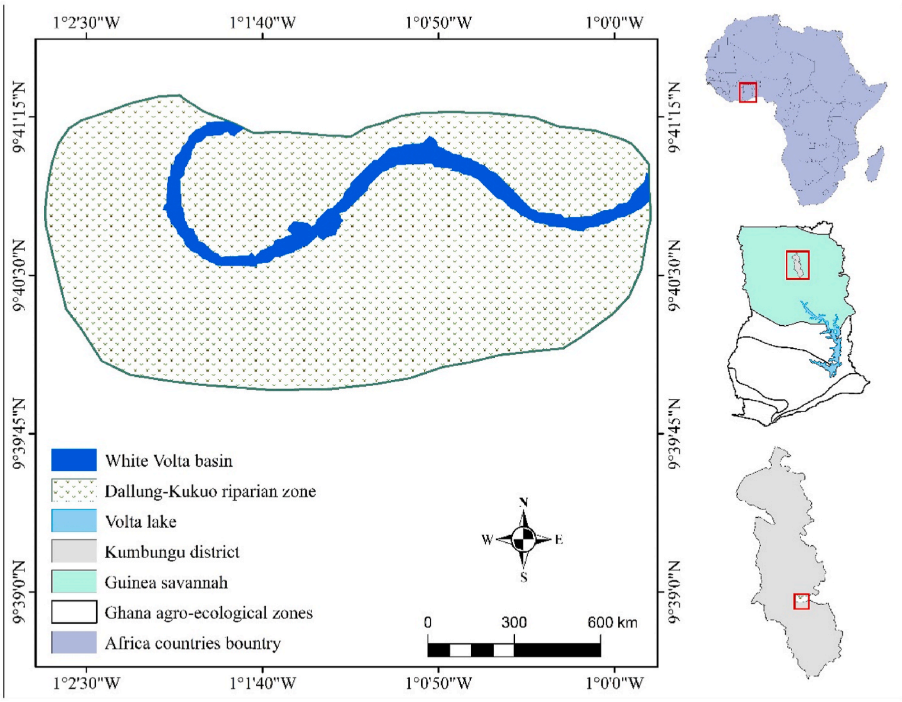


Fig. 1. Map of Dallung-Kukuo catchment of the White Volta Basin.

elevation which serves as an aggregation point for sand washed from upstream areas during the rainy season. Large volumes of sand deposited in the catchment make the area a good site for sand mining in the dry season.

The entire basin is generally characterised by a relatively low relief with an average elevation of 200 m [21] Soils are predominantly Luvisols formed from underlying parent materials of shale, sandstone granite and igneous stones [22]. The vegetation is mainly grassland interspersed with trees and shrubs where *Vitellaria paradoxa* (Shea), *Adansonia digitata* (Baobab), *Ceiba pentandra* (Kapoks), *Parkia biglobosa* (Dawadawa), and *Faidherbia albida* (accasia) are among the most dominant in the landscape. Common grass species include *Panicum* sp., *Heteropogon* sp., *Andropogon* sp., *Pennisetum* sp. among others [23].

Communities in the catchment of the sub-basin are mainly engaged in agriculture as a major livelihood activity. Maize, sorghum, millet and rice are among the common crops cultivated in the area [21]. Although agriculture has been the traditional occupation of communities along the WVB, unreliable rainfall patterns and rapid urbanization have shifted many rural dwellers to other alternative livelihood activities such as fishing, and sand mining.

2.2. Data collection

2.2.1. Image acquisition and field mapping

Satellite images (Landsat 4-5TM and Landsat 7 EMT+) devoid of cloud cover of the catchment area were obtained for the years 1990, 2000, 2010, and 2021 from http://www.usgs.glovis.gov for classification and post-classification change detection (Table 1). The goal was to comprehend the dynamics of land cover in the Dallung-Kukuo riparian zone and to accurately assess the impact of sand mining on riparian vegetation. Except for the 2010 image data which was acquired in May due to the unavailability of image data for the region of interest after May, all images were acquired for November. This approach was used to curb the effect of seasonal variation in the different tiles and ensure that the various land cover seem as they do in reality. Images in November were chosen because it marks the off-set and on-set of the rainy season and dry season respectively and various land covers in the area can be identified on the image easily and classified accurately. The month of May on the other hand marks the early rainy season and as such, all land cover types can easily be identified and classified.

Accurate classification requires robust ground truth data for training samples and validation of the results [24]. Therefore, Garmin GPSmap 62 device was used to map the observed land cover types in the region as Forest Areas (WL), Grassland/Abandoned Sand Areas (GL/ASMA), Water Bodies (WB), and Sand Areas (SMA) in the image classification training set and Validation of classified thematic. Four hundred and fifty (450) ground truth points were taken across all the observed land cover types. The boundaries of the study area were also mapped with the Garmin GPSmap 62 device to help create the area of interest (AOI) file i.e., shapefile of the Dallung-Kukuo sand mining site in ArcMap version 10.8. For the historical imagery (1990, 2000, and 2010), the study relied on Google Earth to select points to aid classification and validation.

2.2.2. Satellite image pre-processing

The acquired image data were unzipped into Tag Image File Format (TIFF) for further processing. The Landsat 7 EMT^{+} images for 2010 and 2021 had scan lines running through them as a result of a faulty sensor on May 31, 2003 [25]. These gaps were filled with the gap mask data that accompanied the faulty images using the "Fill no data" tool in QGIS 3.0 software. The various (corrected) bands (TIFF) for each image data were layer stacked in ERDAS Imagine 2015 software. The layered stacked images underwent radiometric correction using histogram equalization in the ERDAS Imagine 2015 software to correct for different sun angles and changes in surface reflectance, improving detectability in the composite images in a manner used by Ref. [26]. The various images were filtered to further enhance their sharpness using the Standard filters in Erdas Imagine 2015 software. The satellite images have already been projected to WGS 1984 UTM Zone 30 N. Therefore, no geometric correction was required as the study region falls under this coordinate system. Finally, the Dallung-Kukuo sand mining site was subset from the various satellite images using the shapefile (AOI) file created.

2.2.3. Assessment of woody species diversity and abundance

To examine the effect of sand mining on woody species diversity and abundance, quadrates were laid in the sand mining and unmined sites of the riparian zone. This stratification was done to enable a comparison of species diversity in disturbed and undisturbed area of the riparian zone. In each site, six 25 × 25 m quadrates were laid, using a systematic random sampling method in which the first quadrat was laid at a random location and thereafter the subsequent quadrates were laid at a regular distance of 50 m apart. Woody species (trees, shrubs and saplings) were identified and counted per plot. Trees were defined as woody species with diameter at breast height (dbh) greater than 10 cm based on [27] whilst shrubs were woody plants having profuse branches and stems with a dbh greater than or equal to 5 cm as used in Ref. [28]. Saplings on the other hand were woody species that had dbh ranging between 2.5 and 4 cm based on [29].

Table 1
Satellite image characteristics and date of acquisition.

Tile No.	Satellite Image ID	Path/Row	Satellite	Spatial Resolution	Image Date
1	LT05_L1TP_194,053_19,901,106_20,170,128_01_T1	194/053	Landsat 4-5TM	30 m	November 06, 1990
2	LE07_L1TP_194,053_20,001,109_20,170,209_01_T1	194/053	Landsat 7 EMT+	30 m	November 09, 2000
3	LE07_L1TP_194,053_20,100,513_20,161,215_01_T1	194/053	Landsat 7 EMT+	30 m	May 13, 2010
4	LE07_L1TP_194,053_20,211,103_20,211,129_01_T1	194/053	Landsat 7 EMT+	30 m	November 03, 2021

Identification was based on local names (Dagbani) which were cross-checked for corresponding scientific names in Ref. [30] literature on "*Dagomba plant names*". All nomenclature in the study conforms to the International Plant Nomenclature index [31].

2.3. Data analysis

2.3.1. Digital image classification

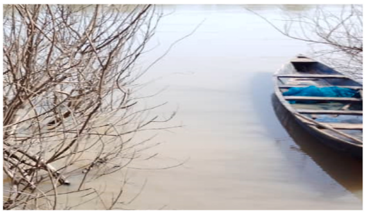
Supervised classification using a maximum likelihood algorithm was applied for the image classification. Maximum likelihood classification is one of the most common and rigorous algorithms employed widely [12,32,7] as the algorithm quantitatively classifies every pixel by evaluating the variance and covariance of the categorical spectral response pattern [10,7]. In the supervised classification technique, the producer trains the algorithm by way of digitizing and grouping pixels based on their categorical spectral reflectance and training points collected from the field into their likelihood of belonging to a specified land cover class. Based on that, the following land cover classes were identified: Woodland (WL) areas, Grassland/Abandoned Sand Mining Areas (GL/ASMA), water bodies (WB), and sand mining areas (SMA) (Table 2).

The area of the individual land cover was calculated in hectares using the pixel count in the classified thematic in ERDAS Imagine 2015 software. Afterwards the land cover thematic map for the different years were produced in ArcMap 10.8 environment.

2.3.2. Accuracy assessment

Accuracy assessment is key to validating how well image pixels are classified or misclassified [27] into a cover class. Accuracy assessment was carried out on all the classified land cover thematics based on the quantity disagreement and allocation disagreement accuracy assessment of [7] alongside omission and commission errors. Quantity discrepancy is the magnitude of the difference between the reference data and the classified thematic due to a less than perfect match in the proportions of the pixels, while attribution discrepancy is the difference between the reference data and the classified thematic due to the less-than-optimal match in the spatial allocation of pixels [7]. A total of 135 ground truth points were used to assess the accuracy of each classified thematic thus 30% of the total (450) points were taken for each of the image data. The accuracy of the classified thematic was computed in the PontiusMatrix41.

Table 2
Description of land cover classes.

Land cover	Description	Picture of the land cover type
WL	Areas occupy by savannah trees and/or shrubs.	
GL/ASMA	Areas which were originally covered by grass/abandoned mined sites that have transformed into grassland.	
WB	Areas holding surface water, particularly the river course	
SMA	Areas where sand mining activities were ongoing at the time of the data collection	

xlsx environment.

2.3.3. Assessment of compliance with the riparian buffer zone policy

Before post-classification change detection, encroachment of the Dallung-Kukuo riparian buffer zone by sand mining activities was investigated for the focal years. The riparian buffer zone policy for managing freshwater bodies in Ghana states that, at least 100 m off the watermark should be designated as a protected area [21]. Based on this policy, a 100-m buffer was created outside the White Volta basin in each of the classified thematic to examine compliance with the buffer zone policy. This was accomplished by using the raster-to-polygon tool in ArcMap 10.8 environment to export the class WB and SMA in the various themes to vector files. The buffer tool in ArcMap 10.8 was then used to establish a 100-m buffer around the White Volta basin for the respective years. The individual

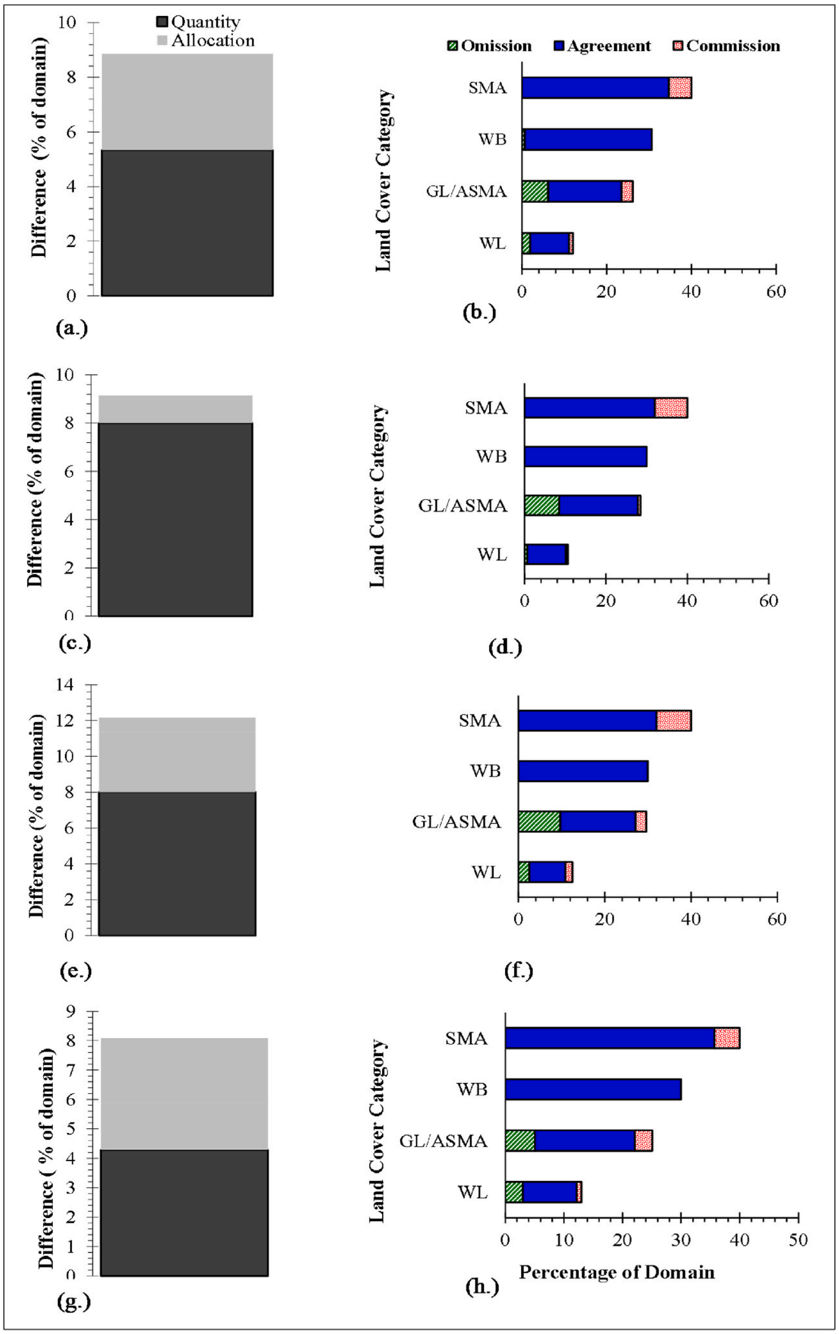


Fig. 2. Disagreement (a, c, e, & g), Agreement, omission disagreement, and commission disagreement (b, d, f, & h) between the classified land cover and reference data.

buffer was finally used to clip the mining activities within the protected buffer for the respective years. An encroachment map was produced based on the White Volta basin (WVB), buffer zone sand mining area (BZSMA), 100-m buffer zone (100 m BZ), sand mining area (SMA) and Dallung-Kukuo riparian zone (D-KRZ).

2.3.4. Post-classification change detection

Post-classification change detection was also employed to assess the changes in land cover over a thirty-one-year period as used by Refs. [33,34]. Two classified images of different years were compared to compute their categorical change using the Matrix Union in Erdas Imagine 2015 software. For instance, the classified image of 1990 was compared with that of 2021 to ascertain which land cover had changed to what over the years.

2.3.5. Woody species diversity and abundance

Shannon Wiener diversity index (H) of woody species was computed separately for mined and unmined sites of the riparian zone using the formula;

$$H = -\sum (Pi \text{ In } Pi) \tag{1}$$

H = Shannon Wiener's diversity index, Pi = Relative abundance of the ith species, InPi = Natural log of the corresponding relative abundance (Pi) of the species (Eq. (1)).

The abundance of woody species in the riparian zone was also estimated from the frequency (absolute and relative), relative density (Eq. (2)) and density (Eq. (3)) of all species encountered based on [35].

$$Relative\ density = \frac{Number\ of\ individuals\ of\ species}{Total\ number\ of\ individuals} * 100 \tag{2}$$

$$Density\ of\ species = \frac{Total\ number\ of\ individuals\ of\ species\ in\ all\ plots\ laid}{Total\ area\ of\ the\ plot\ laid} \tag{3}$$

3. Results and discussion

3.1. Post-classification accuracy assessment

Post-classification image validation was carried out to affirm the relationship between classified data and the reference data from ground truthing. The accuracy assessment report for 1990 (Fig. 2 a & b), 2000 (Fig. 2 c & d), 2010 (Fig. 2 e. & f), and 2021 (Fig. 2 g & h).

The overall disagreement between 1990, 2000, 2010, and 2021 classified land cover and the reference data was 8.8%, 9.2%, 12.1%, and 8.1% respectively, many of which was due to quantity disagreement. The omission was higher in class GL/ASMA, whereas commission was higher in class SMA, indicating the tendency of misclassifying some pixels of these classes across the study area domain. The overall disagreement values recorded in this study are less than that of [36] who recorded a mean disagreement of 13.2%.

3.2. 2 landuse/landcover of the Dallung-Kukuo catchment from 1990 to 2021

In 1990, the woodland (WL) area recorded the largest land cover type constituting 58.4% of the riparian zone (Table 3). The woodland area was spatially dominant in the north-eastern and western portions of the Dallung-Kukuo riparian zone (Fig. 3).

This is an indication that a substantive landmass of the riparian zone was occupied by woody species and served as a transition zone that could effectively regulate ecological processes in both terrestrial and aquatic ecosystems [13]. Moreover, this woodland could also protect water bodies especially, the sub-basin of the White Volta against erosion, and water evaporation, and also filter soil sediments and nutrients from runoff.

Grassland/abandoned sand mining area (GL/ASMA) covered 24.8% of the riparian zone. GL/ASMA dominated the southern portion of the area (Fig. 3). These are areas that were either originally covered by grasses or regained grass cover through auto-recovery. Water bodies constituted 14.1% of the total riparian landmass and runs through the middle of the riparian zone. However, the sand mining area recorded the least land size of 2.7% and was spatially evident in the north-western region of the area (Fig. 3).

Table 3
Land cover statistics for Dallung-Kukuo catchment from 1990 to 2021.

LULC	1990	%	2000	%	2010	%	2021	%
	Area		Area		Area		Area	
WL	639.6	58.4	520	47.5	508.8	46.5	420.6	38.4
GL/ASMA	271.1	24.8	266.6	24.4	333.7	30.5	335.7	30.7
WB	154.1	14.1	109.7	10	107.5	9.8	146	13.3
SMA	29.9	2.7	198.4	18.1	144.7	13.2	192.4	17.6
Total	**1094.7**	**100**	**1094.7**	**100**	**1094.7**	**100**	**1094.7**	**100**

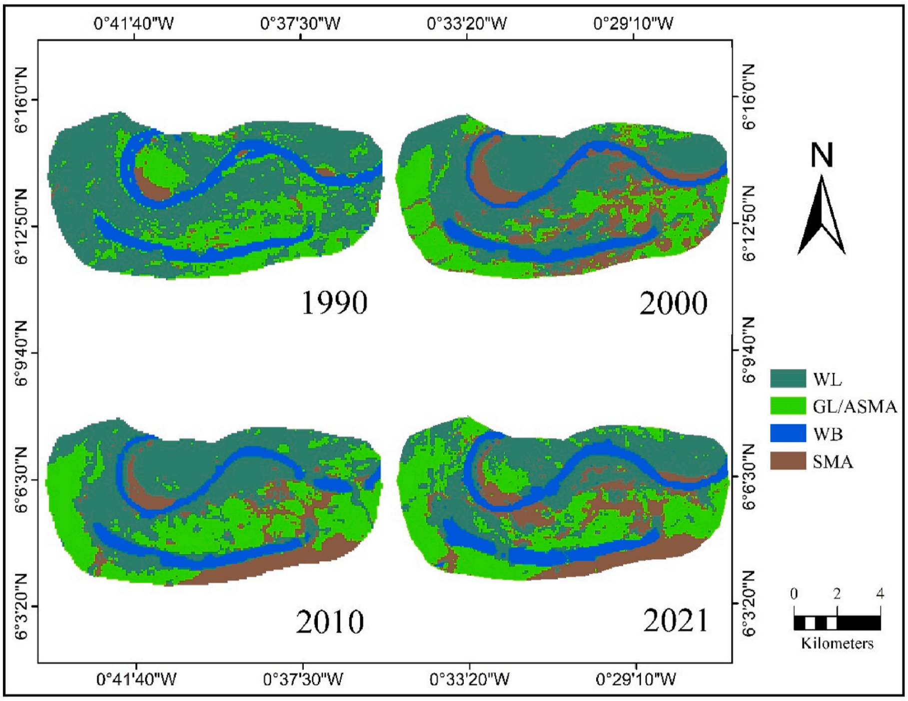


Fig. 3. Spatio-temporal distribution of land cover types in the Dallung-Kukuo.

The limited sand mining recorded in 1990 could be attributed to low urbanization in the 1990s. Urbanization necessitates the expansion of houses and industries to meet the needs of urban and peri-urban areas.

In 2000, WL areas had reduced from the 58.4% in 1990 to 47.5% and GL/ASMA also had a minor decline from 24.8% in 1990 to 24.4% (Table 3). These landcovers were spatially abundant in the northern and western portions of the riparian area respectively. The decline in the woodland area could be an evidence of sand mining among other factors as the sand mining area (SMA) recorded a significant gain of 18.1% of total land size compared to the 2.7% recorded in 1990 (Table 3). This finding is consistent with [37], who reported that sand mining reduced woodland area in Wa Municipality due to tree removal in the mining process. The rise in the construction industry to meet housing needs coupled with employment (source of income) offered by mining contractors tends to motivate the youth to engage in sand mining activities [37]. Trees act as natural bio-filters for underground and surface water [11]. The implication of reduced woodland cover is increased siltation and eutrophication of the White Volta as loosened soil particles and chemical fertilizers are easily washed in run-off [11]. The rooting system of trees serve as a natural filter of debris and soil sediments.

Moreso, the removal of woody species in the area exposes the surface water to extreme temperatures which have contributed to the declining water bodies from 14.1% in 1990 to 10% in 2000 (Table 3). This finding confirms [18], who revealed that the river basin of the Nawuni catchment has reduced with increasing farmland area.

Again, in 2010, WL experienced a minor decline from 47.5% in 2000 to 46.5%. However, GL/ASMA underwent a substantial rise from 24.4% in 2000 to 30.5% which was spatially distributed across the western, southern, and eastern portions of the riparian zone. Self recovery after the mining activities could have led to the gain in GL/ASMA. This is based on the fact that grasses are often the pioneer species after serious soil or land perturbation. Also, areas covered by water bodies (WB) and SMA declined from 10 to 9.8% and 18.1 to 13.2% respectively (Table 3).

Human activities such as sand mining in the riparian zone could have contributed to the decline in WL and WB while increasing grassland and bare lands [18]. The reduction in SMA in 2010 could be an indication that the intensity of sand mining activities in the area reduced. This could be attributed to the relocation of some sand miners to the Nawuni catchment when the quantity of sand had reduced in Dallung-Kukuo. This assertion confirms a report issued by the Ghana Water Company Limited (GWCL) in 2019 to shut down its water treatment plant due to high turbidity levels of water associated with sand mining activities in the river basin (https://www.graphic.com.gh/news/general-news/ghana-news-gwcl-to-shut-water-treatment-plant-at-dalun-due-to-sand-winning-activities.html).

Finally, in 2021, WL area further decreased from 46.5% in 2010 to 38.4% whereas GL/ASMA witnessed a slight increase from 30.5% in 2010 to 30.7% (Table 3). Comparatively, the areas covered by WL over the thirty-one [38] year period revealed a constant decline in the woodland cover that gives rise to GL/ASMA. This implies that important ecosystem services provided by the woody plants in protection and conservation of the river could be curtailed.

On the contrary, areas covered by water bodies have increased from 9.8% in 2010 to 13.3% in 2021 (Table 3). This could be an outcome of the amount of rainfall received in 2021 coupled with the spillage of excess water from the Bagre dam, one of the largest dams in neighbouring Burkina Faso [39,40]. The water level varies with the season and year, depending on rainfall and drought conditions [41]. Sand mining in the Dallung-Kukuo riparian zone could render the place flood prone in the case of torrential rain or excess spill-over from the Bagre dam. The changing landcover patterns could also increase susceptibility to drying during years of erratic rainfall due to reduced vegetation cover for enhanced infiltration and reduced evaporation [41].

3.3. The effects of riparian buffer zone policy compliance on clean water

Sustainable development goal six [42] is to ensure access to water and sanitation for all by 2030. The Ghana Water Company Limited (GWCL) water treatment plant at Dalung supplies potable water to residents in Tamale, Savelugu, Tolon, Kumbungu, and its environs (Fig. 4). It can be deduced that sand miners have encroached on the buffer zone of the Dallung-Kukuo catchment. This action of sand miners could contribute to a high level of siltation with consequences on the amount of water intake by the GWCL treatment plant and the cost of treating the water for human consumption. This could result in water shortages and also affect the achievement of SDG 6 at the local level.

3.4. 1990–2021 land cover change trajectories of Dallung-Kukuo catchment

The Spatio-temporal distribution of land cover change and the change statistics (Figs. 5 and 6) revealed that, the original woodland area had declined by 10.9%. The original grassland/abandoned mine area has also reduced by 0.4%. The original areas covered by water bodies have declined by 4.1% (Fig. 5). In contrast, the sand mining area recorded a significant gain of 15.4%. It could be deduced from the results that sand mining is the prime cause of the alteration in the land cover of Dallung-Kukuo catchment.

From 2000 to 2010, the woodland area continued to decline by 1% whereas, grassland/abandoned mine area recorded an increase of 6.1% (Fig. 6), with patches occurring in the central and eastern parts of the riparian zone (Fig. 5). The areas covered by water bodies however witnessed a marginal loss of 0.2% (Fig. 6). This could be due to the reduction of the storage capacity of the White Volta basin as sand miners often fill up some tributaries and peripheries of streams to make the place accessible to trucks.

From 2010 to 2021, the woodland area continued to decline by 8.1% whereas, grassland/abandoned mine area recorded a marginal increase of 0.2%. The areas covered by water bodies also witnessed a rise of 3.5% (Fig. 5) due to the amount of rainfall received coupled with the spillover of excess water from the Bagre dam. Moreso, the sand mining area increased by 4.4%, with the change more visible in the central parts of the riparian zone (Fig. 5).

Finally, from 1990 to 2021, the woodland area continued to decline by 20% whereas, grassland/abandoned mine areas recorded a significant increase of 5.9%. The areas covered by water bodies also witnessed a loss of 0.7% (Fig. 6). However, the sand mining area increased substantially by 14.9%, with the change spatially occurring at the central and southern parts of the riparian zone (Fig. 5). The implication of this finding is that if current trends of riparian woodland degradation persist the ability of the riparian vegetation to provide essential ecosystem services would be loss.

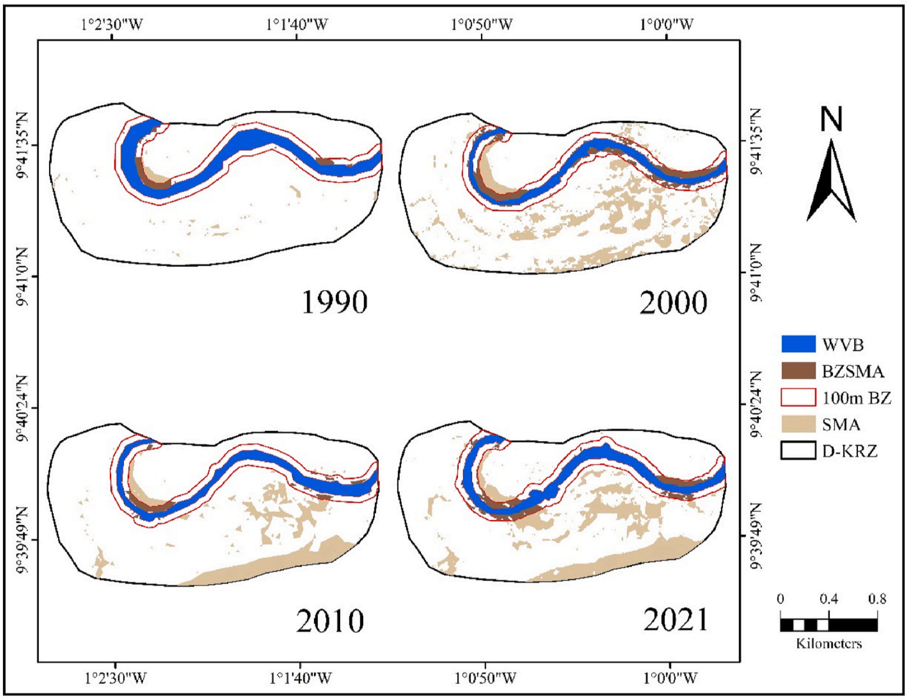


Fig. 4. Encroachment of Dallung-Kukou Dallung-Kukuo catchment.

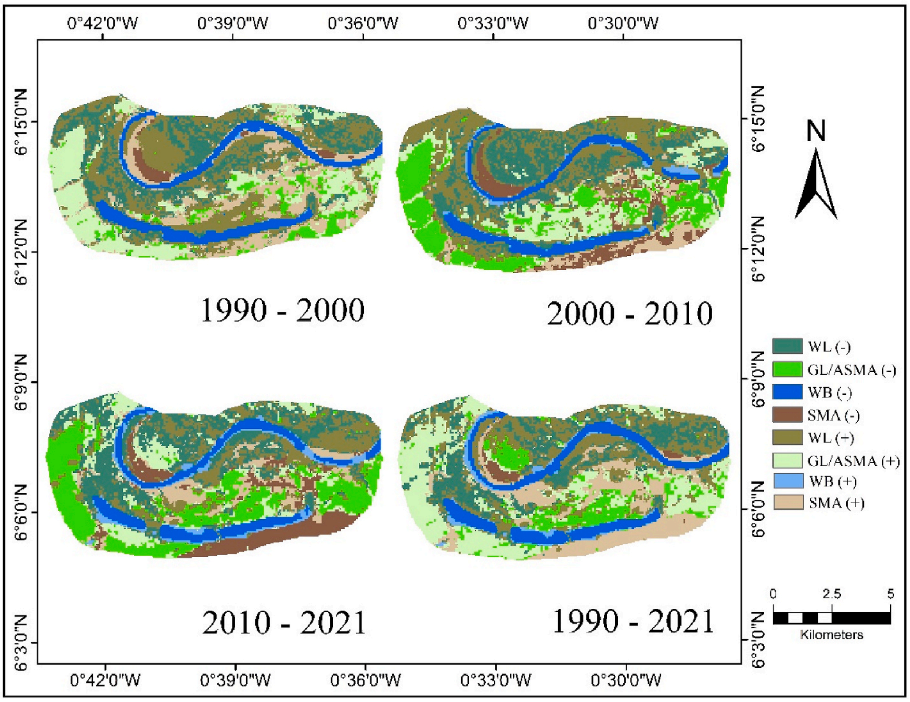


Fig. 5. Spatial distribution of land cover from 1990 to 2021.

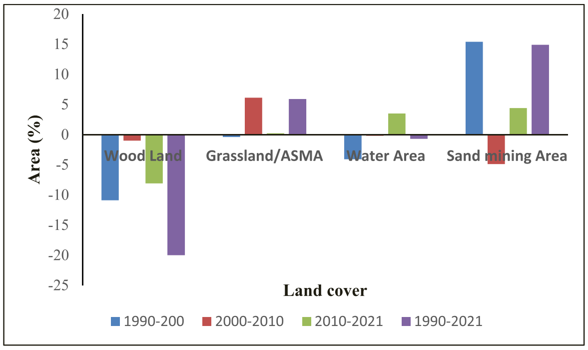


Fig. 6. Land cover change dynamics in Dallung-Kukuo catchment.

3.5. Floristic composition of the woody species in the riparian zone

A total of twenty-three [31] species belonging to twelve [27] families were identified in the Dalung-Kukuo catchment of the riparian zone. The families Leguminosae, Meliaceae, and Combretaceae were the most dominant in the catchment (Table 4). This finding is similar to Ref. [33] who reported, Leguminosae, Moraceae, Meliaceae among the dominant woody plant families in the forest-savanna ecotone of Ghana. Similarly [37], recorded Meliaceae, and Leguminosae among the dominant plant families in Sudan Savanna zone of Ghana. Leguminosae and Combretaceae have frequently been recorded as dominant families in many other studies in Ghana [43,42,44].

3.6. Woody species diversity and abundance in the riparian zone

Shannon diversity indices were computed to compare woody species diversity between the mined and unmined sites. The Shannon diversity index accounts for the abundance and evenness of the species present in an area of interest [45]. The value of the Shannon Weiner diversity index usually ranges between 1.5 and 3.5, and hardly exceeds 4.5 [46,47,48,49,50]. In this study, the unmined site had a Shannon diversity index of 3.0 $\pm$ 0.07 whilst the mined site recorded an index of 2.0 $\pm$ 0.05. The Unmined site of the riparian zone recording a Shannon index of 3.0 $\pm$ 0.07 indicates a reasonably high species diversity.

Table 4
Woody species richness and abundance in the riparian zone.

Family	Richness		Relative Richness		Abundance		Relative Abundance	
	X	Y	X	Y	X	Y	X	Y
Leguminosae	10	2	48	22	135	17.5	40	21
Moraceae	1	1	5	11	35	17	10	20
Rhamnaceae	1	1	5	11	15	10	4	12
Meliaceae	2	1	10	11	32	15	10	18
Ebenaceae	1	1	5	11	40	12	12	14
Tiliaceae	1	1	5	11	17	5	5	6
Sapotaceae	1	0	5	0	10	0	3	0
Combretaceae	2	0	10	0	37	0	11	0
Myrtaceae	1	0	5	0	5	0	1	0
Anacardiaceae	1	0	5	0	10	0	3	0
Balanitaceae	0	1	0	11	0	5	0	6
Rubiaceae	0	1	0	11	0	2.5	0	3
Total	**21**	**9**	**100**	**100**	**336**	**84**	**100**	**100**

X = Sand mine site of the catchment, Y = Unmined site of the catchment.

This implies that the integrity of woody species in the unmined site is intact and capable of providing ecosystem services such as food, habitat for wildlife, and protection of the river from siltation and pollutants. According to Ref. [38], riparian vegetation is known to contain diverse species of ecological and socio-economic significance. The Shannon index (3.0) recorded for the unmined site is dissimilar to the finding of [50] who reported a Shannon index of 3.5 in the Kenikeni forest reserve in northern Ghana. Similarly, a Shannon index of 3.4 was recorded in the Banda district and Kintampo municipality of Ghana [51].

However, the Shannon diversity index of 2.0 recorded in the mined site can be classified as moderate based on [49]. The moderate diversity recorded in mined area may be attributed to the removal of vegetation in the process of sand mining. Sand mining, like other anthropogenic disturbances, has negative impacts on the diversity, evenness, and abundance of species [37].

4. Conclusion

The riparian land cover change detection for the Dallung-Kukuo catchment of the White Volta basin revealed a rise in sand mining activities with a corresponding loss in woody vegetation coupled with shrinking river course. Sand mining activities have equally affected the diversity of woody species in the riparian zone. It is therefore evident that, if current anthropogenic disturbances persist, there would be a high risk of losing the integrity of the woodland cover of the riparian zone. This would have cascading effects on quality and quantity of water available for human consumption in the area. Stakeholders such as the Local Government and Environmental Protection Agency should intensify monitoring of sand mining activities to help protect the river basin.

Author contribution statement

Latif Iddrisu Nasare - Conceived and designed the experiments; analyzed and interpreted the data; Wrote the paper.
Stephanie Asabea Opoku - Performed the experiments; wrote the paper.
Amos Amponsah -analyzed and interpreted the data; wrote the paper.
Damian Tom-Dery- analyzed and interpreted the data; wrote the paper.
William J. Asante - Wrote the paper; analyzed and interpreted the data.
Bernard N. Baatuuwie - Wrote the paper; analyzed and interpreted the data.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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