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Land use and land cover changes in sub-catchments of Zimbabwe and their implications on wetland and catchment soil water conditions

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A R T I C L E I N F O

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A B S T R A C T

This study evaluated land use and land cover changes in the Shashe and Tugwi and Zibagwe sub-catchments from 2017 to 2023, with a focus on their impacts on dry season wetland extent and condition. Utilizing the Google Earth Engine Cloud Computing platform, Sentinel-2 Level 1C data were processed using Support Vector Machine (SVM) classification algorithm to analyse these changes. The Soil Moisture Active Passive level 4 (SMAP L4) soil moisture and the Normalised Difference Vegetation Index (NDVI) were computed to determine the influence of catchment level land cover change on soil moisture conditions. This study considered the influence of land cover on wetland conditions and catchment level soil moisture levels which got minimum attention in previous wetland studies. The study highlights that bare land in Tugwi and Zibagwe increased more rapidly (601.1 %) than in the drier Shashe sub-catchment. However, the wetland area decreased more in Shashe, indicating greater wetland degradation despite the slight difference (0.4 %). The analysis revealed that wetlands experienced an overall 11.8 % loss in Shashe and 11.4 % loss in Tugwi-Zibagwe. Results indicate that 5.2 %, 3.4 % and 2.3 % of the wetland area was replaced by grassland, shrubland and bare land respectively in Tugwi and Zibagwe combined whilst 4.8 %, 3.6 % and 2.32 % of the wetland area were replaced by bare land, grassland and shrubland respectively in Shashe. Statistically significant weak positive correlations were confirmed between soil moisture and NDVI in Tugwi and Zibagwe combined ($r = 0.28; p = 0.04$) and Shashe ($r = 0.43; p = 0.02$). Rainfall had stronger correlation with soil moisture in Tugwi and Zibagwe ($r = 0.43; p = 0.19$) and Shashe ($r = 0.62; p = 0.38$) which were not statistically significant indicating more influence of land cover on soil moisture than rainfall. The findings accentuate the critical need for sustainable land use practices to mitigate the adverse effects on natural land cover and wetland ecosystems. The rapid expansion of bare land and reduction in wetlands underscore the pressing challenges posed by land cover changes, particularly in regions experiencing increasing aridity.

1. Introduction

Wetlands are vital ecosystems that provide several ecological, socio-economic benefits (Napreenko et al., 2021; Nayak and Bhushan, 2022). However, they are facing increasing pressure from human activities like agriculture, urbanisation and deforestation, which characterise major drivers of catchment -level hydrological and ecological changes (Musasa and Marambanyika, 2022; Gxokwe et al., 2024). Decreased water storage and increased sedimentation are some major physical consequences of land cover changes, especially the loss of vegetation and an increase in bare land surfaces (Aghsaei et al., 2025). Therefore, wetlands suffer from agriculture and deforestation that loosen soils, resulting in siltation and poor infiltration in deforested areas. This underscores the need to understand land use and cover changes within hydrological catchments and how the spatial coverage of wetlands responds to those changes (Aghsaei et al., 2025). However, there seems to be a paucity of information on how land use changes influence wetland extent, especially in areas that experience different climatological conditions and human activities. Such information informs sustainable land use practices through informed policy and decision making, as far as landscape management and resource conservation are concerned.

A study in the Anzali wetland catchment, Gilan, Iran, confirmed the influence of land use and cover changes on sediment yield and catchment hydrology, especially the impacts of agriculture on increased

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evapotranspiration (Aghsaei et al., 2025). This shows that land use and cover changes can negatively affect water storage through sediment accumulation in wetlands within such areas. However, this was only a catchment for an individual wetland, which lacks a broader perspective of larger geographical areas like sub-catchments with several wetlands surrounded by various human activities. Riverine ecosystems suffer through altered flow regimes, as confirmed in Tanzania, where land use and land cover changes had negative impacts on flow regimes of the Great Ruaha River (Kashaigili, 2008). Usually, wetlands shrink during the dry season as an indication of decreased water supply in a hydrologically altered catchment. This was supported by Kashaigili (2008) during their study in the Great Ruaha River Catchment in Tanzania. The changes in flow regime were linked to an increase in agricultural activities like irrigation in the upstream of the catchment. This indicates the negative implications of land uses in the catchment have on wetland areas. However, the influence of land cover change on wetland area extent in these studies seems to be generalized without indicating statistics on wetland areas that were encroached by human activities like agriculture or croplands. The present study seeks to cover that loophole. Though the general implications are known, the differential implications of land use in drier and wetter catchments are understudied. Human activities like agriculture in agro-based economies and societies in semi-arid areas are driven by the need to produce more food under changing climatic conditions. This is likely to make a difference in wetland utilisation between areas that receive better rain and those that are extremely arid. Knowledge on how wetland exploitation, as well as human activities that affect catchment hydrology, differ in these areas is important as it results in commensurate measures for land use management and wetland conservation in dry and comparatively wetter areas. This makes the present study of significant importance.

In some developing countries of semi-arid regions of the world, the majority of studies focussed on the impacts of human activities on naturally vegetated areas with limited link to wetland extent responses as the case in Gubalafito District of north eastern Ethiopia (Abebe et al., 2022), Jimma Geneti District in western Ethiopia (Hailu et al., 2020), Ward 32 of Mazowe District in Zimbabwe (Matsa et al., 2020), Shurugwi District, Zimbabwe (Muringaniza et al., 2024) Matabeleland South province, Zimbabwe (Maviza and Ahmed, 2020), South west Nigeria (Peter et al., 2023) to mention just few. These studies made strong analyses of drivers of land cover changes and the major implications on naturally vegetated landscapes, as they did not focus on hydrological catchments. This calls for the need to prioritise the spatial and temporal response of water/wetland areas to the observed changes in human activities across larger geographical spaces to inform wetland conservation policy and decision making.

Some studies drew attention to the implications of land cover changes within catchments of individual wetlands (Rashid et al., 2023; Zekarias and Gelaw, 2023) or hydrological catchments with similar climatological conditions (Mfwango et al., 2022; Mupepi and Chinyemba, 2024). This limited discussion on how drivers of land cover changes are shaped by climatological conditions, especially rainfall and temperature, as well as soils, which determine the intensity of wetland utilisation (Musasa and Marambanyika, 2022). Zekarias and Gelaw (2023) focused on the catchment area of Lake Abaya-Chamo in Ethiopia, where land uses around this wetland affected water cover extent, whilst Thonfeld et al. (2020) focused on similar aspects in the Kilombero wetland hydrological catchment. Informed by these studies, there is a need to broaden the spatial scope of studies that focus on land use and cover-wetland extent nexus to larger geographical areas with more than one wetland to ensure broader conclusions and the development of conservation strategies.

A recent study by Gxokwe et al. (2024) on large -scale wetland change dynamics in the Limpopo transboundary basin considered the influence of land use change on wetland extent change across regions with different climatological conditions. It covered Southern Zimbabwe, Botswana and South Africa, but the discussion on differences in land use changes taking place in different climatological zones and distinct impacts on wetlands was minimal. Despite this limitation, it is one of the few studies that paid attention to catchment level land cover changes and their implications on wetland extent and condition across different climatological regions. Against this background, this study seeks to analyse the implications of land use and cover changes on wetland spatial extent in two sub-catchments with different agro-ecological conditions. This improves an understanding of the implications of land cover changes on wetlands and how they are shaped by human activities in different catchments found in different agro ecological regions. The specific objectives of this study are to: 1) map dominant land use and cover transformations and 2) analyse their implications on wetland area extent and catchment soil water in Shashe, Tugwi and Zibagwe sub-catchments between 2017 and 2023. This will lead to knowledge on land use and cover changes in wetlands located in different hydrological catchments found in agro-ecological regions, Zimbabwe. This information will enhance decision making as far as sustainable land use management and wetland conservation are concerned, thus contributing to the achievement of Sustainable Development Goals 14 and 15 on life below water and life on land, respectively.

2. Materials and methods

2.1. *Study area*

The study was conducted in three Zimbabwe sub-catchments namely Zibagwe sub-catchment (6 87950 ha), in the Sanyati catchment, Tugwi sub-catchment (7 90760 ha) in the Runde catchment and Shashe sub-catchment (19 02140 ha) in the Mzingwane catchment (Fig. 1). The fact that the Shashe sub-catchment is larger than the Tugwi and Zibagwe sub-catchments led the authors to merge Tugwi and Zibagwe (Tugwi-Zibagwe) into one hydrological catchment with a size almost comparable to the Shashe sub-catchment. This was also made easy as these two sub-catchments share a boundary and experience almost a similar climate. The sub-catchments are located in different agro-ecological zones. Zimbabwe is divided into five agro-ecological zones (AEZs) based mainly on precipitation, temperature and soil suitability for agriculture (Manatsa et al., 2020). Rainfall and temperature decrease and increase, respectively, from AEZ 1–5b, whilst soil suitability for agriculture declines in the same order. The Shashe sub-catchment falls in AEZ 4–5b. The soils are characterised by shallow coarse grained kaolinitic sands, sand loams and clays emanating from the greenstone belts and shallow sands derived from basalts and low mean annual rainfall ranging between 450 and 600 mm (Manatsa et al., 2020) and Annual average temperatures in Shashe range between 31 and 35 °C. Higher rainfall is received in the northern parts of the sub-catchment.

The whole of Zibagwe sub-catchment and the greater northern part of Tugwi sub-catchment fall under AEZ 3, which receives a mean annual rainfall of 635 mm and experiences maximum temperatures of between 28 and 33 °C (Mashizha et al., 2017; Chanza and Gundu-Jakarasi, 2020).

The southern part of the Tugwi sub-catchment is in AEZ 4, which receives a mean annual rainfall of 600 mm. In all study catchments, rainfall and temperatures continue to decline and increase, respectively (Ndebele-Murisa and Mubaya, 2015; Sibanda et al., 2020), which potentially impacts the hydrological regime of the wetlands and affects rain-fed agriculture. Tugwi and Zibagwe sub-catchments are hydrologically dependent on the Driefontein wetland, located at their watershed (Fig. 1). This drives land uses in both sub-catchments, which made it necessary to combine the two sub-catchments as Tugwi-Zibagwe in this study. Shashe sub-catchment has lower population density (14 per km2) than Tugwi and Zibagwe sub-catchments (37 per km2), which have the potential of influencing land cover and wetland conditions differently. Shashe and Tugwi sub-catchments are largely communal in terms of land use, whilst Zibagwe is dominated by large -scale commercial farming areas and resettlements. Shashe has larger protected land, which include Matopo National Park and a Sanctuary around the Tuli

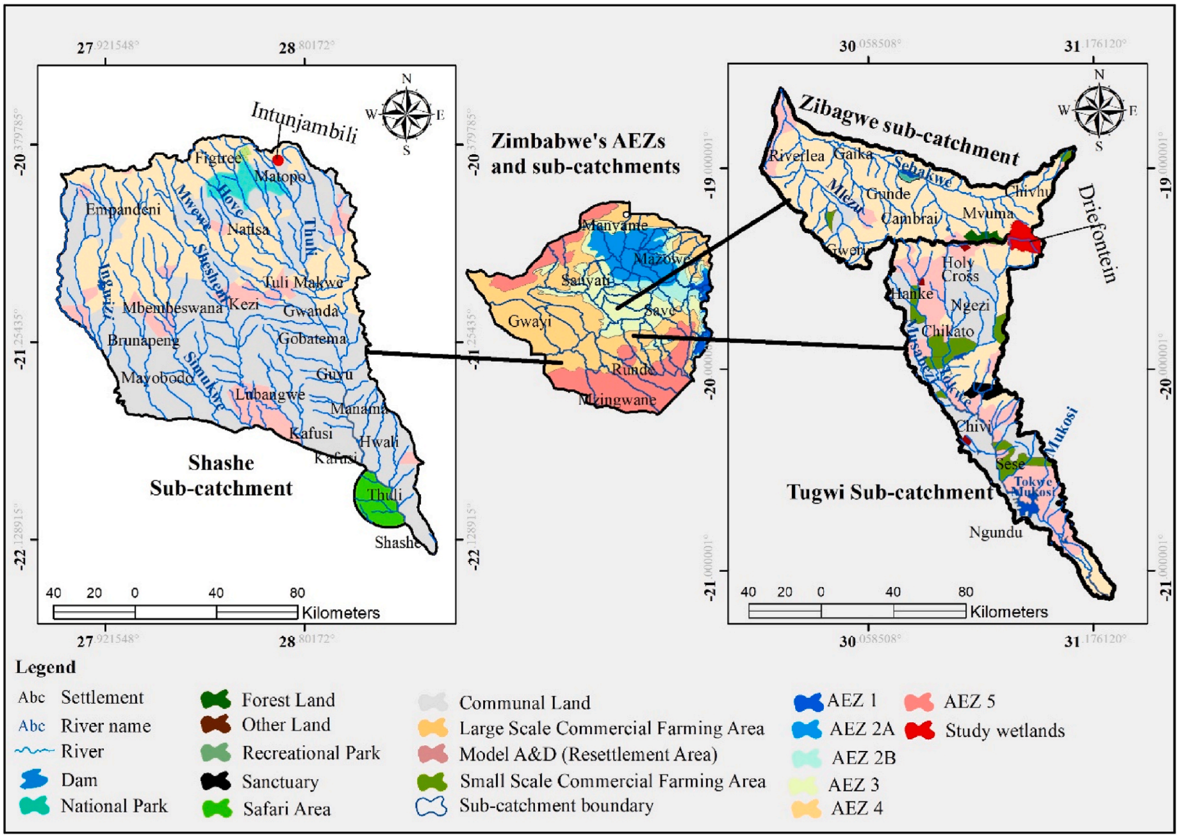

Fig. 1. A map showing the location of Shashe, Tugwi and Zibagwe sub-catchments Zimbabwe.

area. These differences in land uses may also determine differences in land use and cover changes due to varying intensity of human activities. This makes it imperative to understand land cover changes in these different hydrological catchments and how land use and cover changes influence wetland extent and condition. Shashe, being dry, is dominated by Colophospermum mopane and Acacia vegetation species, whilst Tugwi and Zibagwe are dominated by Brachystegia spiciformis, Julbernadia globiflora and some mopane and Acacia species found in the southern drier parts of Tugwi sub-catchment.

The combined population for the Mangwe, Matobo and Gwanda districts within the Shashe sub-catchment is 285 806 whilst the combined population for the Chirumhanzu, Vungu, Kwekwe, Chikomba, Chivi, Masvingo and Shurugwi districts in the Tugwi-Zibagwe sub-catchments is 1 046 841 (Zimbabwe National Statistics Agency, 2022). Rain-fed agriculture and livestock production, which constitute the major sources of livelihoods, are being affected by increasingly dry conditions, which leave exploitation of wetlands for irrigation and community gardens, especially in Shashe, as an alternative. The situation is comparatively better in most of the areas in Tugwi and Zibagwe sub-catchments, where higher rainfall and good soils for agriculture, like red loamy and sandy loam soils in the central and northern parts of this area, make rain-fed agriculture more possible. This also explains the dominance of resettlement areas to which people migrated for agriculture during the land redistribution process between 2000 and 2005. However, wetland agriculture is also being increasingly practised in Tugwi and Zibagwe as frequent drought continues to affect rain-fed agriculture (Musasa and Marambanyika, 2022). These areas are characterised by significant wetland agriculture activities as communities try to cushion themselves against the increasing impacts of climate change induced rainfall variability and droughts.

2.2. Field data

Field work was done between October and November 2023 to appreciate the available land covers in the study areas and collect co-ordinates for the identified land covers. For the 2017 to 2022 period, ground truthing points were collected from the high resolution reference map within the Google Earth Engine platform since no field visits were done. A handheld Global Positioning System Receiver version Garmin etrex was used to collect at least 30 coordinates from each of the 7 land cover types (cropland, thick woodland, sparse woodland, water/wetland, grassland, bare/cultivated land and shrubland) in Tugwi and Zibagwe combined and in Shashe sub-catchments. This was done because Shashe (19 02140 ha) is slightly larger than Tugwi and Zibagwe combined (1478710 ha). In this case Tugwi and Zibagwe were merged into one study area that at least compares with the size of Shashe. Field points were added to 50 ground truthing points per land cover that were derived from the high resolution reference map in GEE in Tugwi and Zibagwe combined and Shashe. This translated to a total of 80 samples per land cover and 560 per sub-catchment for all land covers. Combining field samples and high resolution mage samples was only done for the year 2023 when the field data was available. However, all the sampling points were derived from high resolution reference image for the other years (2017, 2019 and 2021). The classification algorithms were trained using 70 % (56 per land cover) of the ground truthing samples whilst the remaining 30 % (24) were reserved for validation using the confusion matrix.

2.3. Data acquisition and pre-processing

Orthorectified Top of Atmosphere (TOA) reflectance Sentinel-2 level-1C products with sub-pixel multispectral registration were acquired using the Google Earth Engine (GEE) Catalogue. Layer stacks of images acquired between September and October 2017, 2019, 2021 and

2023 were filtered by cloud cover (<1 %) (.filter (ee.Filter.lt ('CLOUDY_PIXEL_PERCENTAGE',1)), date (1 September −30 October) for instance, year 2017 (.filterDate("2017-09-01″, "2017-10-30″) and region of interest (ROI) (.filterBounds(ROI)) using Shashe and combined Tugwi and Zibagwe shapefiles (Fig. 2). Median composites for these layer stacks were determined to get the best images with pixels with best radiometric quality and minimised atmospheric contamination and shadow by using the code:. median (). The period 2017–2023 was determined by the availability of Sentinel products for the mapping of land use and cover changes in the study areas. Through the GEE platform, the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) version 2.0 and the Soil Moisture Active Passive level 4 (SMAP L4) for the period 2017–2023 were derived to retrieve rainfall and soil moisture data.

The availability of Sentinel-2 products for the study area started in 2017 which made it the baseline year of study. Sentinel-2 products were prioritised due to their higher spatial resolution (10 m) compared to other free sensors like Landsat and MODIS which allowed for detection of smaller patches of land cover that can be omitted at 30 m and 500–1000 m resolution. The year 2023 was the most recent with available images for September and October. The months of September and October were selected because they mark the season when various land covers can be easily identified and distinguished. This applies especially on bare/cultivated lands, irrigation lands and grasslands (Murwendo et al., 2023). This period also experiences less to no cloud cover which enhances the quality of acquired images through reduced radiometric noise (Prudente et al., 2020). Two-year intervals were chosen to ensure greater detail on temporal changes in land use and cover whilst avoiding yearly change detection when the changes could be insignificant.

2.4. Image processing for land cover classification

Median composite images developed from the acquired layer stacks were adjusted to true colour composites for visual identification of land covers to employ supervised image classification. Random Forest (RF) supervised image classification algorithm was selected after outperforming the Support Vector Machine (SVM) and CART supervised classification machine learning algorithms (Fig. 2). This was noted after running supervised image classification using all these algorithms and computation of accuracy assessments to confirm the best classification accuracy using the same training samples for all the classification methods. This was made possible by using GEE platform to replace and run each classification algorithm within few seconds. This confirmed recommendation by previous studies that selected Random Forest as the best classification algorithm (Sheykhmousa et al., 2020; Gxokwe et al., 2022a,b). Training samples were generated from 7 land covers identified which include cropland, thick woodland, sparse woodland, water/wetland, grassland, bare/cultivated land and shrubland (Table 1). These land covers were classified based on the authors' observation and knowledge from other published literature on land cover classification (Gxokwe et al., 2022a,b; Moharram and Sundaram, 2023a,b; Murwendo et al., 2023)

Table 1
Land covers and their description in the study context.

Land cover	Description in the study context.
Water/wetland	Open water or highly saturated areas
Bare/cultivated	Barren land without vegetation and areas cultivated/tilled for crop production. Built-up areas were incorporated under this class as most of them had similar spectral signatures to bare and cultivated lands which had impacts on classification accuracy.
Thick woodland	Pixels dominated by trees with thick canopy cover indicating dense woody vegetation.
Sparse woodlands	Pixels dominated by woody vegetation or trees which do not have thick canopy cover usually having patches of grass or shrubs between them.
Shrubland	Pixels dominated by small bushes or shrubs
Grassland	Pixels dominated by grasses
Cropland	Pixels dominated by irrigated crops

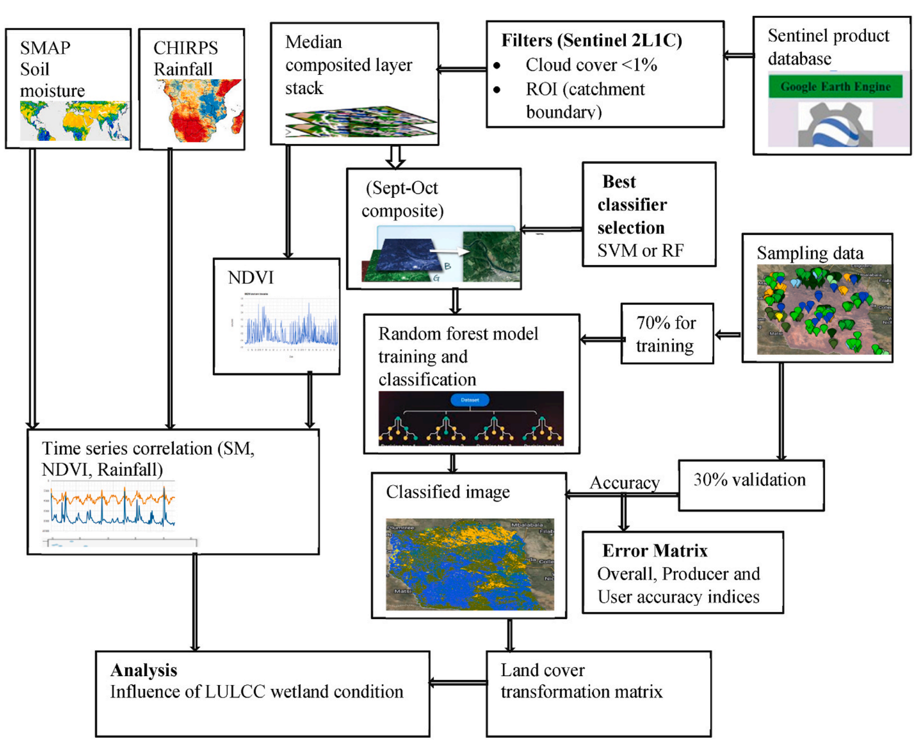

Fig. 2. Methodology flow chart.

2.5. Catchment level land cover and moisture condition analysis

Though land cover change and water/wetland area extent were determined using basic image classification, it was important to understand how overall land cover changes especially loss of vegetation to other land uses in each of Shashe and Tugwi-Zibagwe sub-catchments influenced overall soil moisture conditions in the upper 2-m soil layer inclusive of wetlands and non-wetland areas. Therefore, volumetric water content data from the Soil Moisture Active Passive level 4 (SMAP L4) and Normalised Difference Vegetation Index (NDVI) from Sentinel-2 L1C product were derived as proxies of overall catchment soil water content and land cover condition respectively, between 2017 and 2023 (Fig. 2). The daily Root Zone Soil Moisture (RZSM) that is moisture within the upper 2-m soil layer was retrieved from SMAP L4 through GEE whilst the NDVI was computed using the formula developed by Rouse et al. (1973). The NDVI was chosen based on its capacity to indicate the subtle changes in catchment level vegetation decrease or bare area increase which would show the trajectories in land cover condition between 2017 and 2023. The RZSM was chosen to indicate catchment level moisture condition changes at a depth of 2-m inclusive of wetlands and non-wetland areas. Time series soil moisture and NDVI (mean monthly values for January 2017 to December 2023) were derived using GEE for the period between 2017 and 2023 to ascertain the overall relationship that exists between land cover and catchment soil water content. To strengthen the analysis of the influence land cover on soil moisture, monthly rainfall data was derived from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) version 2.0 for the period 2017–2023. This was done to compare the influence of land cover and rainfall on the observed trends in soil moisture. The Pearson correlation was run to confirm the relationship between moisture, NDVI and land cover change between 2017 and 2023.

2.6. Accuracy assessment

Accuracy assessment of the classified images was done using the error matrix where classified images were compared to 30 % of the samples collected from the field and reference images (Fig. 2) (Foody, 2002; Sari et al., 2021). The overall accuracy (OA), producer accuracy (PA) and user accuracy (UA) were computed to determine the accuracy of the classified images. The overall accuracy was computed as a basis for determining the overall efficiency of the adopted classification algorithms whilst the producer accuracy and user accuracy indices were used to measure the probability that the reference samples were correctly classified on the maps and the classified pixels accurately represent ground truth respectively. On the GEE platform the code "sample = sample. randomColumn(); var trainingSample = sample.filter ('random ≤ 0.7′); var validationSample = sample.filter('random >0.7′); was used to split the samples into 30 % validation and 70 % training. After this, the confusion matrix was then computed using thecode, "validationSample = validationSample.classify(trainedClassifier); var-validationAccuracy = validationSample.errorMatrix (label, 'classification'); print('Validation error matrix', validationAccuracy); print ('Validationaccuracy', validationAccuracy.accuracy()); ".This was important to ensure that the classified images were reliable and useable to make conclusions on land cover changes in the two study sub-catchments.

3. Results

3.1. Classification accuracy

The overall accuracies for the four classified images ranged between 76 % and 93 % which indicates acceptable classification accuracy based on Random Forest algorithm. The 2017 images for Shashe and combined Tugwi and Zibagwe sub-catchments had 87 % and 93 % classification accuracy respectively whilst the 2019 and 2021 images had 89 % and 87 % and 93 % and 76 % respectively. In terms of producer and user accuracies, they ranged between 70 % and 98 % in Tugwi and Zibagwe sub-catchment and 76–100 % in Shashe sub-catchment with higher accuracy on water/wetland and lower accuracy on shrubland and grassland.

3.2. Major land cover features in shashe and Tugwi-Zibagwe sub-catchments

Sparse woodland dominates in the Shashe sub-catchment as it has been fluctuating between 44.6 % and 50.6 % of the total land cover between 2017 and 2023. This was followed by shrubland, which fluctuated between 27.4 % and 25 % of the total land cover. Grassland and thick woodland have fluctuated between 14.2 % and 12.6 % and 12.6 % and 10.4 % of the catchment area respectively, between 2017 and 2023 (Fig. 3).

Water/wetland and cropland fluctuated between 0.12 % and 0.1 % and 0.03 and 0.05 % respectively between 2017 and 2023. For Tugwi-Zibagwe, shrubland has been dominating, fluctuating between 28.1 % and 40.6 % followed by grassland which fluctuated between 24.7 % and 37.1 % over the study period. Just like in the Shashe sub-catchment, water and cropland proved to be the smallest land covers which fluctuated between 0.9 % and 0.8 % and 0.02 % and 0.1 %, respectively. Wetland area is less than 1 % in both catchments, which indicates that they cover a very small portion of the area.

Water/wetland area decreased by 27 % between 2017 and 2019 in the Shashe sub-catchment in response to a 72.3 % increase in bare land, whilst in Tugwi-Zibagwe water/wetland area dropped by 15.3 % when compared to a 59.8 % increase in bare land during the same period. This could be a result in increased crop cultivation and wetland agriculture activities. In the Shashe sub-catchment bare land dropped by 68 % between 2019 and 2021, whilst in Tugwi-Zibagwe it increased by 99.4 %. Water/wetland area increased by 26 % in Shashe, whilst it increased by 81.3 % in Tugwi-Zibagwe (Table 2). This might be due to the better 2020/21 rainy season in both sub-catchments.

3.2.1. Major land cover transformations in shashe, Tugwi and Zibagwe sub-catchments between 2017 and 2023

Findings indicated that the major transformations included changes from thick wood to sparse wood (6.1 %) in Shashe and thick wood to grassland (7.1 %) in Tugwi and Zibagwe combined (Fig. 4; Table 3).

Other major transformations in Tugwi-Zibagwe included thick wood to sparse wood (6.3 %), sparse wood to shrubland (6.1 %), sparse wood to grassland (5.7 %), shrubland to bare (4.1 %), grassland to shrubland (2.5 %), grassland to bare (2.0 %), thick wood to shrubland (2.8 %) and shrubland to sparse wood (1.7 %) (Fig. 4; Table 3). When comparing the two sub-catchments, they both experienced increased sparse woodland due to the loss of thick woodland and increased grasslands due to the loss of shrubland. More of Tugwi and Zibagwe's changed areas developed from woodland into grassland and shrubland, whilst in Shashe, it was thick wood to sparse wood and grassland from sparse wood and shrubland. Water/wetland area was mainly encroached by grassland (0.01 %) and bare land (0.01 %) in Shashe sub-catchment, and grassland (0.1 %), bare land (0.01 %) and shrubland (0.01) in Tugwi-Zibagwe sub-catchments. This indicates drying up of wetland or water covered area, which is being replaced by bare, grass and shrubs. Though the wetland area transformed into bare land and grass is less than 1 %, this is a significant modification considering that the wetland area is very small (<1 %) in both catchments.

3.3. Land use and cover changes in shashe and Tugwi-Zibagwe sub-catchments and their implications on wetland extent between 2017 and 2023

Water/wetland area in both Shashe and combined Tugwi and

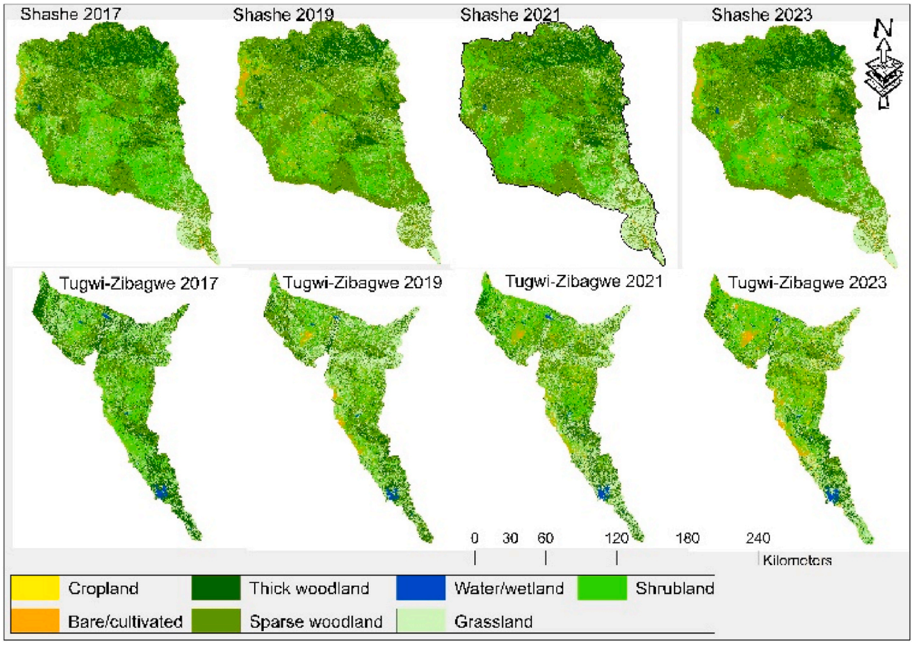

Fig. 3. Land covers in Shashe and Tugwi-Zibagwe sub-catchments between 2017 and 2023.

Table 2
Land cover change statistics for Shashe and Tugwi-Zibagwe subcatchments between 2017 and 2023.

	Shashe sub-catchment land cover in km^2 (percentage cover in brackets)						
	Cropland	Bare	Thick wood	Sparse wood	Water/wetland	Grassland	Shrubland
2017	6.3 (0.03)	177.6 (0.9)	2427.7(12.6))	8477.9 (44.6)	23.5 (0.12)	2702.2 (14.2)	5209.0 (27.4)
2019	3.9(0.02)	305.9 (1.6)	1792.2 (9.4)	10271.9 (54)	17.0 (0.09)	2549.2 (13.4)	4083.9(21.5)
%Change	−37.1	72.3	−26.2	21.2	−27.7	−5.7	−21.6
2021	9.7 (0.05)	98.0 (0.52)	1986.5 (10.4)	9459.2(49.7)	21.4(0.1)	2825.0 (14.9)	4624.2 (24.3)
%Change	147.2	−68.0	10.8	−7.9	26.0	10.8	13.2
2023	9.1(0.05)	263.0 (1.4)	1969.0 (10.4)	9618.7(50.6)	20.7(0.1)	2387.7(12.6)	4755.8(25.0)
%Change	−7.1	168.4	−0.9	1.7	−3.3	−15.5	2.8
Overall change (%)	44.5	48.1	−18.9	13.5	−11.8	−11.6	−8.7
	Tugwi-Zibagwe sub-catchment land cover in km^2 (percentage cover in brackets)						
2017	3.4(0.02)	139.3(0.9)	3119.1(21.1)	3579.3(24.3)	125.0(0.9)	3647.2(24.7)	4137.7(28.1)
2019	9.3(0.06)	222.5(1.5)	1619.4(11.0)	3854.5(26.1)	71.2(0.5)	5469.1(37.1)	3505.1(23.76)
%Change	171.0	59.8	−48.1	7.7	−43.1	50.0	−15.3
2021	3.3(0.02)	443.7(3.01)	1983.6(13.5)	2949.8(20.0)	129.0(0.9)	4699.6(31.9)	4542.0(30.8)
%Change	−64.6	99.4	22.5	−23.5	81.3	−14.1	29.6
2023	14.3 (0.1)	1043.5(7.1)	1680.5(11.4)	2189.0(14.8)	110.8(0.8)	3724.1(25.1)	5988.9(40.6)
%Change	334.2	135.2	−15.3	−25.8	−14.1	−20.8	31.9
Overall change (%)	316.5	649.2	−46.1	−38.8	−11.4	2.1	44.7

Zibagwe sub-catchments experienced negative changes. Specifically, in the Shashe sub-catchment, water/wetland area dropped by 27.7 % between 2017 and 2019, increased by 26 % by 2021 and dropped again by 3.3 % by 2023 (Fig. 5). In the Tugwi and Zibagwe sub-catchments combined, water/wetland area decreased by 43.1 % between 2017 and 2019 before increasing by 81.3 % in 2021 and dropping by 14.1 % in 2023. Overall, Shashe sub-catchment lost 11.8 % of its water/wetland areas whilst Tugwi and Zibagwe combined lost 11.4 % of water/wetland area between 2017 and 2023. Some improvements in water/wetland cover were observed in all study areas between 2019 and 2021 (Fig. 5).

Of the 11.4 % wetland area that was lost in Tugwi and Zibagwe combined between 2017 and 2023, 5.2 % was replaced by grassland, whilst 3.4 %,0.29 % 0.2 % and 0.1 % were encroached by shrubland, cropland, sparse woodland and thick woodland respectively. This indicates that most wetland areas were transformed into bare lands and grasslands in the Tugwi and Zibagwe sub-catchments. In the Shashe sub-catchment, 4.8 % and 3.6 % of the 11.8 % lost wetland area between 2017 and 2023 changed to bare land and grassland. The other changes that occurred in the wetland included encroachment by shrubland (2.3 %), sparse woodland (0.6 %), cropland (0.4 %) and thick woodland (0.08 %). Generally, the statistics point towards more change of wetland area to bare land, grassland and shrubland in Shashe. When comparing Shashe and Tugwi-Zibagwe, more wetland area changed to bare land in Shashe, whilst in Tugwi and Zibagwe, most wetland area has changed to grassland. Overall, both bare land and grassland dominated wetland encroachment in both sub-catchments.

3.3.1. The relationship between catchment level NDVI as a proxy of vegetation cover and root zone soil moisture in shashe and Tugwi-Zibagwe sub-catchments

Results show that NDVI has been fluctuating towards lower values between 2017 and 2023, with average values changing from 0.24 to 0.16 in 2017 to 0.130 and 0.128 in 2023 in Tugwi-Zibagwe and Shashe sub-catchments respectively (Fig. 6).

When it comes to root zone soil moisture, both catchments experienced fluctuation towards negative values between 2017 and 2023.

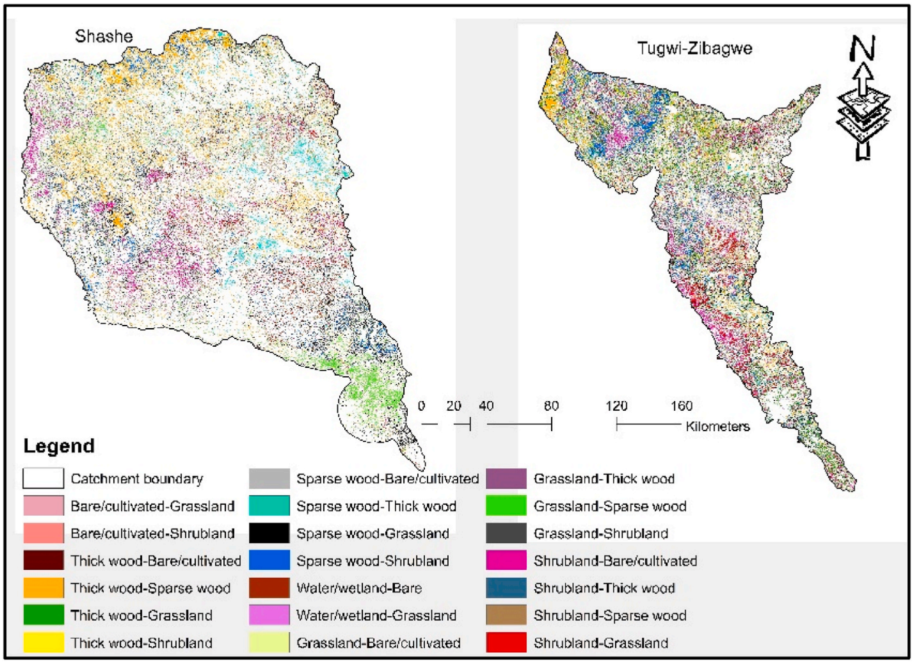

Fig. 4. Land cover transformation in Shashe and Tugwi-Zibagwe sub-catchments between 2017 and 2023 (The white colour indicates areas that remained unchanged). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Land cover transformation matrix for Shashe and Tugwi-Zibagwe sub-catchments between 2017 and 2023.

Shashe sub-catchment							
	Cropland	Bare	Thick Woodland	Sparse Woodland	Water /Wetland	Grassland	Shrubland
Cropland	0.02	0.000	0.02	0.01	0.000	0.001	0.01
Bare	0.000	1.8	0.000	0.002	0.000	0.1	0.7
Thick Woodland	0.01	0.002	13.1	6.1	0.01	0.1	0.1
Sparse Woodland	0.002	0.01	1.6	34.1	0.003	3.6	1.9
Water/Wetland	0.000	0.01	0.00	0.004	0.4	0.01	0.004
Grassland	0.002	0.1	0.03	0.2	0.01	7.9	1.8
Shrubland	0.01	2.9	0.01	1.2	0.001	2.4	18.2
Tugwi-Zibagwe sub-catchment							
Cropland	0.021	0.001	0.000	0.02	0.000	0.01	0.018
Bare	0.004	2.6	0.001	0.03	0.000	0.2	0.3
Thick Woodland	0.01	0.1	10.3	6.3	0.1	7.1	2.8
Sparse Woodland	0.03	0.3	1.5	15.1	0.02	5.7	6.1
Water/Wetland	0.000	0.01	0.004	0.001	0.9	0.1	0.01
Grassland	0.01	2.0	0.8	0.05	0.02	15.0	2.5
Shrubland	0.03	4.1	0.1	1.7	0.000	5.3	9.0
Key	Red = Major changes; Light blue = No changes ; Uncoloured =Minor changes						

Though soil moisture has been fluctuating between highs during the wet season and lows during the dry season, annual averages dropped from 0.17 to 0.13 in 2017 to 0.14 and 0.12 in Tugwi-Zibagwe and Shashe sub-catchments respectively (Fig. 6). This shows a slight negative change in soil moisture within the top 100 cm soil layer at catchment level in response to a decrease in vegetation cover as indicated by drops in NDVI values in Tugwi-Zibagwe and Shashe sub-catchments.

Correlation analyses on the relationship between soil moisture and NDVI indicated a statistically significant weak positive correlation between root zone soil moisture and NDVI ($r = 0.43; p = 0.01$) in Shashe sub-catchment, whilst in Tugwi and Zibagwe combined, the relationship was weak and statistically insignificant ($r = 28; p = 0.07$) (Table 4).

This indicates that decreased vegetation cover negatively affects soil moisture. When NDVI and soil moisture were correlated to rainfall in all sub-catchments, soil moisture had a strong positive correlation with rainfall in Shashe ($r = 0.62; p = 0.38$) and a weak positive relationship in Tugwi and Zibagwe combined ($r = 0.43; p = 0.18$). When it comes to NDVI and rainfall, statistically significant and very weak positive correlations were confirmed in both Shashe ($r = 0.03; p = 0.001$) and Tugwi and Zibagwe combined ($r = 0.05; p = 0.002$) (Table 4).

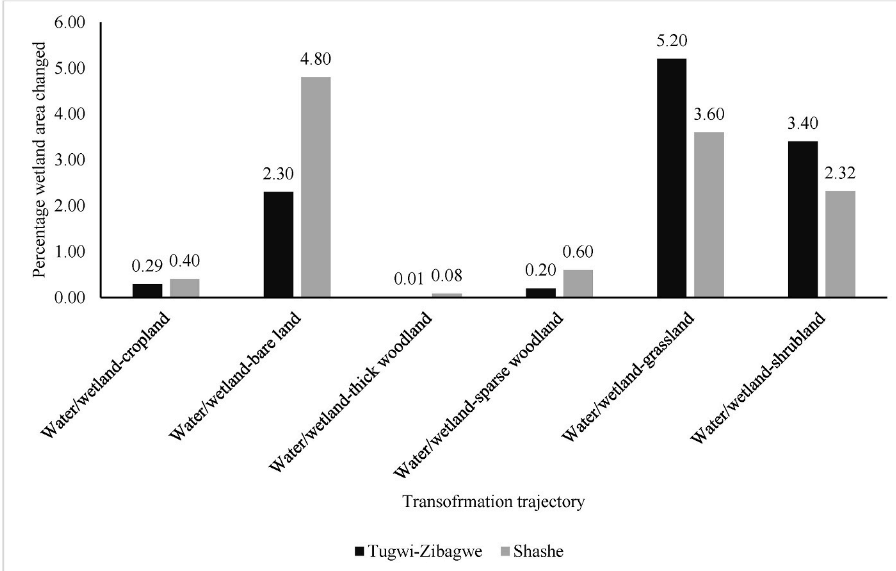

Fig. 5. Land cover change-induced wetland loss in Shashe, Tugwi and Zibagwe sub-catchments between 2017 and 2023.

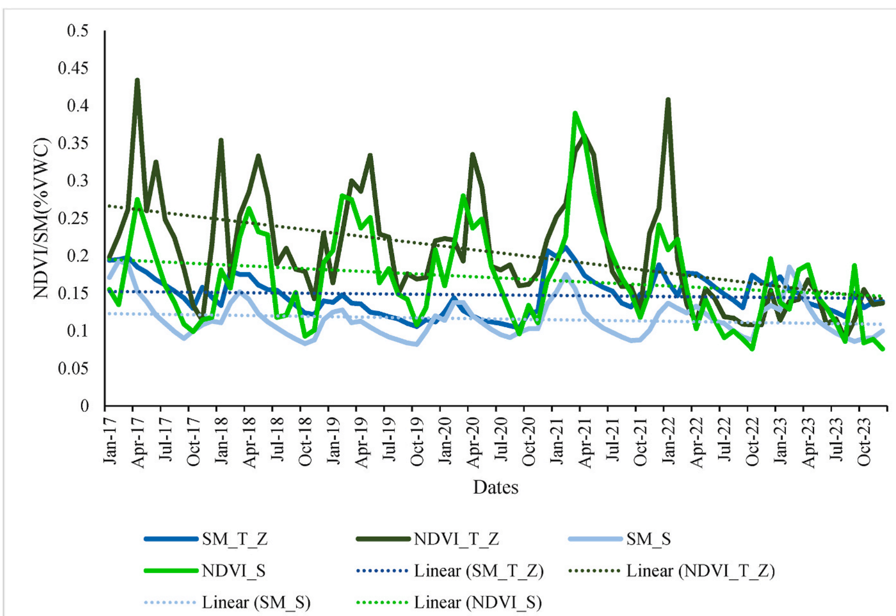

Fig. 6. Catchment average monthly NDVI and soil moisture distribution in Shashe, Tugwi and Zibagwe sub-catchments between 2017 and 2023 (T_Z = combined Tugwi and Zibagwe, S=Shashe, SM = soil moisture).

Table 4
Correlation between SMAP root zone soil moisture, NDVI and rainfall in Shashe, Tugwi and Zibagwe sub-catchments.

	SHASHE		
Variables	RZSM	NDVI	RAIN
RZSM	**1**	0.431 (0.018)	0.621 (0.38)
NDVI	0.431 (0.18)	**1**	0.034 (0.001)
RAIN	0.621 (0.38)	0.034 (0.001)	**1**
	TUGWI-ZIBAGWE		
RZSM	**1**	0.280 (0.041)	0.430 (0.185)
NDVI	0.280 (0.041)	**1**	0.045 (0.002)
RAIN	0.430 (0.185)	0.045 (0.002)	**1**

4. Discussion

4.1. Major land cover features in shashe and Tugwi-Zibagwe subcatchments

The increasing dominance of sparse wood and shrubland in the Shashe sub-catchment and the increasing dominance of shrubland and grassland in Tugwi-Zibagwe sub-catchments were observed. This can be explained by higher population density (37 per km^2) (ZIMSTAT, 2022) and associated activities like crop cultivation, resettlements and wood abstraction for various uses in Tugwi-Zibagwe than in Shashe (14 per km^2). This is supported by findings from a study by Chikodzi et al. (2013), which indicated that wetter agro-ecological regions have more human activities, mainly rain-fed crop production, than drier areas. This is one of the reasons why the Shashe sub-catchment has more natural landscapes with less disruption when compared to the Tugwi-Zibagwe sub-catchment.

The degree of aridity as defined by low rainfall and high temperatures (Manatsa et al., 2020) negatively affects dryland farming, which impedes extensive rain-fed agriculture and promotes livestock production in the Shashe sub-catchment (Ndlovu et al., 2020; Hove et al., 2022). This is almost the opposite in Tugwi-Zibagwe sub-catchment, where higher precipitation and lower temperatures (Makarati et al., 2021) promote dryland cultivation leading to extensive crop cultivation in the catchment. This results in increases bare lands and settlements which results in land clearance and many other disturbances. Kurukulasuriya et al. (2006) indicated that predictions show that dryland farming will be hardest hit by climate change in Southern Africa, a scenario that appears to be taking place in this current decade, mainly affecting agro-ecological regions 4 and 5 in Zimbabwe. This drove away farmers from dryland farming activities in the dry Shashe sub-catchment, who are now concentrating on irrigation and wetland cultivation (Marambanyika, 2015). This explains the loss of wetland area at the expense of crop production. More so, literature indicates that mining activities are more pronounced in Tugwi-Zibagwe, especially in areas around Kwekwe, Gweru, Shurugwi and Chirumhanzu districts (Matsa and Muringaniza, 2011; Muringaniza et al., 2024). This led to serious deforestation, which led to shrubland and grassland dominating, a scenario confirmed in Shurugwi District (Matsa and Muringaniza, 2011; Muringaniza et al., 2024) and the upper Runde sub-catchment (Mupepi and Chinyemba, 2023), which are in the same area. More so, given that 93 % of the rural population relies on wood for fuel in Zimbabwe, higher population density in Tugwi-Zibagwe has undoubtedly contributed to more loss of woodland than in Shashe (ZIMSTAT, 2022)

The wetland area was found to be less than 1 % in both catchments, which suggests their concentration in a few areas that remain less disturbed. Shashe had a smaller proportion of its land cover occupied by wetlands, averaging 0.1 % whilst Tugwi-Zibagwe had an average of 0.8 % of the land cover occupied by wetland between 2017 and 2023. This indicates that Tugwi-Zibagwe has a better proportion of its land covered by wetlands, which may be a function of better precipitation and lower temperatures (Mugandani et al., 2012; Manatsa et al., 2020). This promotes positive water balance and hence more surface water resources. Gxokwe et al. (2024) confirmed that the wetland area in the Limpopo River Basin ranged between 0.3 and 2 % which is not too far from 0.1 to 0.9 % observed in Shashe and Tugwi-Zibagwe. This indicates almost similar trends in wetland coverage and changes in semi-arid countries. Due to increasing dry conditions in both catchments, crop irrigation, though covering the smallest portions in both catchments, is being increasingly practised. This shows that people are shifting to irrigation and wetland cultivation, especially in gardens, to cushion themselves against increasing droughts and erratic precipitation.

The positive change in wetland area between 2019 and 2021 may imply more impact of better rains received in 2021 in the whole of Zimbabwe than land cover changes. Therefore, positive changes in thick woodland between 2019 and 2021 in both catchments might not be mainly a result of anthropogenic activities but improved vegetation canopy thickness due to improved moisture owing to better precipitation that was received in Zimbabwe during 2017, 2018 and 2021. However, conservation measures, especially in Matopos National Park in Shashe sub-catchment and plantations and natural forest conservation in Mtao and other areas in Tugwi-Zibagwe might have also contributed to slight positive changes in woodland canopy cover and the ultimate gain in wetland area cover during the same period. Gxokwe et al. (2024) confirmed a similar trend as tree cover replaced some sparse woodlands in the Limpopo River Basin, whose extent includes parts of the Shashe sub-catchment. Shashe sub-catchment experienced fewer changes in all other land covers (sparse wood, water/wetland, grassland and shrubland) when compared to Tugwi-Zibagwe sub--catchment. This was noted on negative changes in woodland, fluctuations in water/wetland area and an increase in shrubland. This shows significant impacts of human activities, mainly agriculture and mining, which are done in the Tugwi-Zibagwe sub-catchment more than in the Shashe sub-catchment.

4.1.1. Major land cover transformations in shashe and Tugwi-Zibagwe sub-catchments between 2017 and 2023

Results showed that land cover changes that occurred in both Shashe and Tugwi-Zibagwe sub-catchments were a result of encroachment of human activities in natural landscapes and degradation of pristine areas into less pronounced natural ecosystems. Over the period 2017 to 2023, thick woodlands were degraded to sparse wood in the Shashe sub-catchment and grassland in the Tugwi-Zibagwe sub-catchment. This emanated from the abstraction of wood by people in both catchments, which is the primary source of energy for 98 % of households (ZIMSTAT, 2022), and possibly increasing dry conditions, which are reducing vegetation health as shown by a drop in NDVI. However, removal of some trees is exposing grass undercover in Tugwi-Zibagwe, whilst removal of some trees in Shashe has mainly reduced the forest thickness. This is because there are large forest landscapes in this sub-catchment which could not quickly deplete but experience reduced canopy thickness. A study conducted by Gxokwe et al. (2024) in the Limpopo River Basin confirmed a different trend, as it indicated that some sparse wood was replaced by tree cover. However, their findings agree that cropland, which included cultivated lands, encroached on some wetland areas.

Sparse wood to grassland transformation in both catchments indicates the loss of shrubs and the exposure of grassland. This might be a result of livestock browsing and the general change in moisture conditions due to climate change -induced droughts. The current bare land was confirmed to have emanated from cultivation and physical degradation of grassland and shrubland in both catchments. Negative change in grassland in Shashe and positive gain in Tugwi-Zibagwe indicate a result of shrubland development in grasslands and loss of woodland respectively. Though changes in thick woodland to bare land was experienced, it was less pronounced in both catchments, which indicates that bare land increase occurred at the expense of shrubland and grassland the most. Results from this study agree with findings from a study by Thamaga et al. (2022) in part of the Limpopo River basin on the South African side, where wetlands were severely degraded due to human activities. These findings provide the basis from which wetland management strategies can be tailor-made for the changes taking place in the study areas and possibly drive the development of frameworks for rehabilitation of unprotected wetlands in rural communities of semi-arid areas, as supported by Thamaga et al. (2022).

Negative changes in cropland experienced in Shashe sub-catchment between 2017 and 2019 and in Tugwi-Zibagwe sub-catchment between 2019 and 2021 show the influence of precipitation supply on the focus on irrigation activities. This might have contributed to positive changes in water/wetland area between 2019 and 2021 in both sub-catchments as water abstraction for irrigation decreased as a result of better precipitation received between 2017 and 2018 in Zimbabwe (Mupepi and Matsa, 2022). This might have possibly promoted rain-fed agriculture, resulting in some farmers relaxing irrigation and wetland agriculture activities while carrying out rain-fed agriculture, thus reducing pressure on wetlands during the period 2019–2021. However, the drying trend, which was noted since 2019, resulted in farmers increasing irrigation supported by the government under different irrigation scheme promotions, as was confirmed to be the case in Shashe (Chitongo, 2021). This explains the general increase in irrigated areas and associated decrease in wetland area by the year 2023.

4.2. Land use and cover changes in shashe and Tugwi-Zibagwe sub-catchments and their implications on wetland extent and catchment moisture between 2017 and 2023

Between 2017 and 2023, pronounced changes in land cover have been experienced in both Shashe and Tugwi-Zibagwe sub-catchments. Cropland and bare land cover experienced more pronounced changes owing to increased crop cultivation, which impacted on water/wetland area through wetland cultivation and exploitation of surface water resources for irrigation. This resulted in the conversion of water/wetland area to bare surfaces or cultivated land. The increase in cropland that encroached on some of the water/wetland areas was a result of quick responses of crop cultivation activities to dynamics in precipitation supply, which is generally decreasing, resulting in shifting towards irrigation and wetland cultivation (Musasa and Marambanyika, 2022). This might have resulted in changes of water/wetland area to grass as surface water resources and wetlands shrank due to the increased demand for water for large -scale irrigation and wetland agriculture (Marambanyika, 2015; Musasa and Marambanyika, 2022). Major positive changes that occurred in irrigated croplands and bare land, including cultivated areas, were the major threats to water/wetland area, which negatively responded especially in the Tugwi-Zibagwe sub-catchment. This was driven by increasing land clearance for crop production and shifting to irrigation to boost crop production in the face of frequent droughts that are affecting Zimbabwe (Mupepi and Matsa, 2022). Cropland increase at the expense of wetland areas was also confirmed in the Shashe sub-catchment between 1995 and 2015 by Sibanda and Ahmed (2021). This indicates that expansion in irrigation activities has been taking place since the 1990s and is putting pressure on surface water resources, leading to a negative trend in wetland area change. The dependence of these irrigation activities on surface water resources like dams and rivers continues to pose negative impacts on wetland areas in the Shashe sub-catchment. The same observation was made in the Marais Poitevin in France, where some marshes changed to just grasslands as a result of climate change and agricultural activities (Godet and Thomas, 2013). Another study in a commonly owned wetland area in Ha Tien Plain, Mekong Delta, Vietnam indicated that a lack of clear land tenure systems resulted in uncontrolled over-exploitation of wetlands, which resulted in replacement of wetland area by crop cultivation and bare lands. This agrees with findings from this study, where commonly owned wetlands, especially in communal land, have been replaced by crops and bare land. This indicates that wetland resources are being degraded at the expense of the quest for food production in wetlands.

The increase in bare land, including cultivated lands at the expense of wetland area, can also be explained by population increase and associated increase in dependence on wetlands for food production. (ZIMSTAT, 2022). In Tugwi and Zibagwe, bare land was continuously increasing whilst some grassland was exposed in areas that used to be water covered, possibly due to other activities like mining, which are more pronounced than in the Shashe sub-catchment (Chikodzi et al., 2013). The greater part of Tugwi-Zibagwe sub-catchments happen to be within the Great Dyke Region where mining activities take place more than southwestern Zimbabwe. This promotes riverine wetland siltation, which replaces water covered or wet areas in the long run.

The loss of vegetation in all study areas is responsible for the replacement of wetland by bare land due to increased sediment accumulation in dams, rivers and small depression wetlands. This was also confirmed to be the case in the Himalayan wetland ecosystem, where sediment accumulation resulted from agricultural and other human activities, resulting in a deceasing extent and condition of the wetlands in this area (Adam et al., 2011). The same finding was confirmed by Aghsaei et al. (2025) in the Anzali wetland catchment, Gilan, Iran, where sediment yield increase was confirmed to be one of the impacts of land cover changes, especially cropland increase and decrease in densely vegetated areas on wetlands. This suggests that the loss of vegetation and an increase in bare land partly contributed to wetland loss. Sibanda and Ahmed (2021) analysed land cover changes in Shashe sub-catchment between 1995 and 2015 and noted a 6 % decrease in wetland area as a result of cultivation and loss of vegetation, a trend that corroborates with findings from this study where wetland areas dropped at the expense of cultivated or bare lands and grasslands. They predicted a 46 % decrease in wetland area by 2045. This agrees with a continuous loss of wetlands confirmed in this study at the expense of an increase in bare land. The change of most water/wetland areas into grassland shows that wetlands are drying up and being replaced by grass, which are possibly seasonal wetlands that have been lost, especially in Tugwi and Zibagwe, where most wetlands are covered by grass. Changes from water/wetland to grass and shrubland indicate the influence of other climatic factors like rainfall and temperature, which result in the drying up of wetlands in naturally vegetated landscapes. A study by Li et al. (2022) on global wetland changes indicated that natural land covers like grass have replaced wetlands more than human activities in the middle latitudes, a scenario that was found in Tugwi and Zibagwe sub-catchments. This was, however, opposite to observations from Shashe, where bare land was the major threat to the wetland area.

It was noted that the overall vegetation cover in the study catchments determined the changes in soil moisture in the top 1-m soil layer, whilst at the same time, rainfall had a slight influence on the long-term catchment wetness. The Pearson correlation analysis indicated that the drop in average catchment level NDVI between 2017 and 2023, due to negative natural land cover changes, affected average catchment level moisture conditions during the same period. Catchment level moisture conditions, including non-wetland areas, showed a negative change, which shows that loss of vegetation and decrease in rainfall both affect catchment hydrology. This was found to be more significant in Shashe than in Tugwi and Zibagwe. However, a more statistically significant influence was confirmed from rainfall than land cover change. This suggests that rainfall is a more important determinant of catchment water content than land cover changes, though both showed notable influence. More so, the influence of rainfall on soil moisture was found to be stronger in Shashe than Tugwi and Zibagwe combined, which suggests that rainfall patterns influence catchment soil water more in the dry Shashe than in wetter Tugwi and Zibagwe combined. Rainfall had a statistically significant, very weak influence on vegetation health, but a stronger statistically insignificant influence on root zone soil moisture in both catchments.

Previous research indicates that rainfall has been on the decline since 2018, except for a positive change that occurred during the 2020/21 rainfall season in Zimbabwe (Mupepi and Matsa, 2021; Mupepi and Matsa, 2022). This might have influenced soil moisture and wetland conditions during this period, as confirmed in this study. A study conducted by Marambanyika (2015) on the influence of rainfall on wetland size change in south-eastern Zimbabwe indicated no relationship between the two variables. This shows that somehow, land use/cover changes have more influence on individual wetlands and catchment hydrology in general.

5. Conclusion and recommendations

The study sought to analyse land cover changes in the drier Shashe and wetter Tugwi-Zibagwe sub-catchments and their implications on wetland extent and soil moisture condition between 2017 and 2023. Results suggest that bare land and cropland are increasing whilst vegetation areas are declining, resulting in a decrease in wetland area. It was noted that the increase in bare land is far faster (601.1 %) in the wetter Tugwi-Zibagwe sub-catchments than drier Shashe sub-catchment. This might be due to more dryland farming in Tugwi-Zibagwe than in Shashe. In light of this, the establishment of frameworks for sustainable land use, which promote conservation of natural landscapes, including wetlands, is recommended. This study is one of the few that tried to analyse the influence of specific land cover changes on wetlands as well as catchment level soil moisture changes due to vegetation loss. Results indicated a combination of agricultural expansion and woodland loss resulted in loss of wetlands. Statistically significant positive relationships between catchment level soil moisture and NDVI in both sub-catchments suggest that land use changes significantly affected catchment water conditions. A stronger and statistically significant correlation between rainfall and soil moisture in Shashe sub-catchment shows that rainfall is the key moisture supply in this dry region unlike in the wetter Tugwi and Zibagwe where ground water is closer. This may suggest accepting the fact that vegetation loss due to land cover transformation significantly influences soil moisture than rainfall changes especially in drier regions. This is a key finding that several studies overlooked in the context of drivers of wetland loss and degradation. In this study, though SMAP soil moisture was ideal for catchment scale soil moisture analysis, it generalized moisture conditions for individual wetlands. This calls for the need to adopt Sentinel 1 radar data to cover that loophole. High resolution radar remote sensing of moisture has the capacity to establish further intricate relationships that exist between land cover and soil moisture. This will lead to the establishment of frameworks for unprotected wetland restoration and land use management in wetland dominated semi-arid zones.

CRediT authorship contribution statement

Oshneck Mupepi: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Conceptualization. **Thomas Marambanyika:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Mark Makomborero Matsa:** Writing – review & editing, Visualization, Supervision, Methodology, Conceptualization. **Timothy Dube:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Formal analysis, Conceptualization.

Consent to participate

All authors participated and agreed to participate up to final revision of the manuscript.

Consent for publication

Authors agreed to let the paper published when considered for publication.

Declaration of competing interest

This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

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Availability of data and material

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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