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Landuse and landcover change assessment in the Upper Runde sub-catchment, Zimbabwe and possible impacts on reservoir sedimentation

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ABSTRACT

This work assesses land cover changes on the Upper Runde sub-catchment, Zimbabwe, and associated effects on sedimentation rates and risks. The model was implemented using the common Geographic Information Systems tools. To achieve this objective, mean annual and monthly rainfall, as well as sediment data, were used (December 2016 and April 2017). Land use and land cover changes were assessed using time-series Landsat data acquired between the years 2000 and 2016. The Revised Universal Soil Loss (RUSLE) model was used to model sedimentation rates in the catchment. Land cover results showed that the catchment experienced significant ($\alpha = 0.05$) changes during the period of monitoring. For example, forests and woodlands decreased by 39% and 23% between 2000 and 2016, respectively. Sedimentation results indicated that the catchment had an average sediment load of 6272 mg/l as compared to the expected maximum of 3000 mg/l. RUSLE soil loss simulation results showed an increase in average soil loss from 1.2 ton/ha/yr. in 2000 to 1.7 ton/ha/yr. in 2016 and an increase in sediment yield by 19.2% from 3476 mg/l in 2000–4144 mg/l in 2016. Overall, the findings of this study demonstrate that the catchment experiences high sedimentation. Therefore, catchment sediment monitoring and soil conservation actions should be a priority.

Author credit statement

Kusena Winmore: Conceptualization; methodology; writing original draft; writing, review and editing, **Chemura Abel**: Methodology; review and editing; formal analysis, **Timothy Dube**: Writing - Review & Editing; Supervision; methodology, **Nicolau Melanie D**: Conceptualization; Writing - Review & Editing; Supervision, **Marambanyika Thomas**: Writing - Review & Editing.

1. Introduction

Almost one percent of the world's water reservoir capacities are lost due to sedimentation, annually (Ghassemi and White, 2007; Hunt 2007; Rahmani et al., 2018). Reservoir storage capacity is of paramount importance for water resource development and security (Rahmani et al., 2018). Although it is almost certain that future water demands will require additional water sources, available reservoirs need frequent and accurate monitoring (Mahmood 1987; Loucks and van Beek, 2017; Peletz et al., 2016). Sediment mitigation is imperative as it helps to minimize the need for new reservoir investment. Traditionally, reservoirs have been designed and operated benefiting from the available storage capacity despite sedimentation levels over a more extended period (Palmieri et al. 2001). The consequences of sedimentation were never taken into consideration, and the impacts have been dire. As such, little efforts have been employed to manage reservoir sedimentation despite the observed inevitable sediment inflow (Wang et al., 2005). The cost of investing in new reservoirs or rehabilitating these reservoirs could be minimised once the rate and levels of sedimentation are established and managed (Hunt 2007).

Reservoir sedimentation costs have been estimated to range between USD 10 to 20 billion per year, worldwide (Annandale and George, 2006). Upon realisation of the impacts of reservoir sedimentation, developed countries have implemented structural and operational procedures to manage sediment discharge into reservoirs. However, for

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developing world, Africa, in particular, information on sediment management to avoid reservoir sedimentation is scanty (Kondolf et al., 2014). This is because most developing countries have a limited inventory of suitable reservoir sites and that buttresses the need for sustainable management of dams (Ghassemi and White 2007; Zambezi River Water Authority 2015). Dam storage capacity reduction is generally exacerbated by rapid changes in land use and land cover in the catchment area of most water sources (Wang et al., 2017). It is to be emphasized that the areas producing more sediment require identification and special priority for the implementation of soil erosion control measures (Bhattarai and Dutta, 2007; Biswas and Pani, 2015).

Zimbabwe is a signatory of the United Nations Convention to Combat Desertification (UNCCD). However, despite participating in the Land Degradation Neutrality Target Setting Programme under the UNCCD, there are few scientific studies that can periodically feed into the degradation reports. Several policy changes including the Fast Track Land Reform (FTLR), Indigenisation and Empowerment, and the Zimbabwe Agenda for Sustainable Socio-Economic Transformation (ZimAsset) have been implemented without an assessment of the impacts on catchment conservation (Dabale and Chiringa, 2014, Rukuni et al., 2006). The upper Runde catchment does not have a sediment load station, but only measures runoff and inflow. Therefore, considering the relationship between catchments conservation and water security, data need to be continuously collected and processed even through modelling techniques in ungauged basins to inform policy and sustainably manage reservoirs (Swarnkar et al., 2018; Tundu et al., 2018). Although technical and mechanical reduction of accumulation or removal of sediment are possible, the viability is questionable, particularly for developing countries (Annandale and George, 2006; Kondolf et al., 2014).

Soil conservation actions remain the most economically viable option (Dymond and Vale, 2018). For instance, catchment land cover is a critical sedimentation factor, and its constant monitoring provides insights about the rate of reservoir sedimentation (Rooseboom and Lotriet 1992; Mavima et al., 2010). Catchment characteristics, such as topography, vegetation cover, lithology, shape, and presence of gullies in the vicinity of the reservoir, can provide a relatively accurate and reliable area-specific sediment yield estimation (Verstraeten et al., 2003; Dymond and Vale, 2018). A reconnaissance study on soil erosion and siltation of dams carried out in the mid-eighties in Masvingo province incorporating the more significant part of Runde catchment showed that over 50% of the 132 small dams were silted. Van den wall Bake (1986) attributed the siltation to decline in forested areas and increased demand for agricultural land. Land use and land cover change is therefore considered as the biggest threat to reservoir storage and usefulness, with deforestation and removal of natural vegetation accounting for 43% of sedimentation of water bodies and hydrological responses are more sensitive to land use and land cover dynamics (Graf et al., 2010; Szabó et al., 2015; Rawat and Singh, 2017; Yadav et al., 2018; Welde and Gebremariam, 2018). It is thus important that the aerial extent of these changes is quantified and frequently updated for a sustainable reservoir management.

Therefore, this study assesses the land use and land cover changes in the Upper Runde sub-catchment as a proxy for assessing and understanding the sedimentation risk of Gwenhoro reservoir. Specifically, the study assesses the rate of land use and land cover change and establish whether the observed changes can be linked to sediment load and annual sediment yield within the Upper Runde sub-catchment area in Zimbabwe. The study findings are important in providing quantitative evidence of the catchment level dynamics that will be used by policy makers and technical catchment managers in planning. The study also answers to the question of analysing the long-term human instigated environmental changes. The findings are useful for achieving Sustainable Development Goals related to poverty reduction (SDG1), clean water and sanitation (SDG6), climate action (SDG13), life below water (SDG14) and life on land (SDG15).

2. Materials and methods

2.1. Study area description

The study was carried out in the Upper Runde sub-catchment ($19^{0}40^{1}$S and $29^{0}50^{1}$E), with specific reference to the Gwenhoro dam (Fig. 1). Upper Runde is a sub-catchment of Runde catchment. The Upper Runde catchment (10,668 km^2) hosts the Gwenhoro dam the second largest water supplier to the City of Gweru. The city has a total population of 157,865 people distributed in 19 residential suburbs (Zimstat 2012). The sub-catchment was predominantly used for commercial farming before the Fast Track Land Reform Programme (FTLRP) was introduced. The Runde catchment occupies 41,000 km^2. The catchment is one of Zimbabwe's seven catchment areas delineated for water resources management. The area receives an average of 600 mm of rainfall per year. Runde catchment conservation is of paramount importance to Zimbabwe and parts of the southern Africa region. The country's two largest human-made surface water bodies used for irrigation, recreation, and tourism are in the Runde catchment, and these are Lake Mutirikwi and Tokwe-Mukosi dam. Tokwe-Mukosi dam is the largest inland water reservoir in the whole country of Zimbabwe. Runde River, which is the main river in this catchment area, drains into Mozambique, where it sustains the many human lives and biodiversity. Monitoring sediment load in the Upper Runde sub-catchment is crucial because it can potentially affect the life and water holding capacity of the numerous water bodies in Zimbabwe and beyond.

The Upper Runde sub-catchment area is dominated by moderately deep fersiallitic soils and grasslands with patches of *Brachystegia* and *Terminalia* species. The catchment is also characterised by pockets of siallitic soils (10%), which are shallow to moderately shallow, and brown or reddish-brown clays. Ordinarily, the soils are not susceptible to erosion. The soils have high productivity potential, depending on the available water. This attribute makes the study area attractive to crop production. The dominant livelihood activities in the sub-catchment area are crop farming, livestock rearing, and artisanal mining. These activities can significantly change the land cover and introduce conditions that are ideal for accelerated soil erosion, such as overgrazing, vegetation clearance, and open pits surrounded by loose soils.

2.2. Image classification

2.2.1. Remote sensing data

Landsat imagery for the years 2000 and 2016 were downloaded from the Global Land Cover Facility (GLCF) (http://glcf.umd.edu/data/landsat/) and USGS earth Explorer (http://usgs.earthexplorer.com) for land use and land cover change detection in the Upper Runde sub-catchment area. The study used images downloaded during the same period of the year, that is, in August/September (Table 1). Dry season images were used to reduce vegetation quality variation that may cause misinterpretation of the land cover classes. Randomly selected sampling points data were determined using a handheld Garmin 60 Global Positioning System (GPS) receiver as ground reference data for accuracy assessment and classification for the 2016 image ($N = 206$). For the 2000 image, visual interpretation of the true colour image and Google Earth were used for training and validation points' collection ($N = 221$). The two Landsat (ETM+ and OLI) scenes were obtained in digital number (DN), and were atmospherically corrected using the dark object subtraction method.

The imagery for the year 2000 was chosen as a baseline because the catchment is assumed to have after that experienced characteristic changes from the inception of the Fast Track Land Reform programme that caused deforestation in most localities in Zimbabwe (Dalu et al., 2013). Land use and land cover change as a result of land tenure change is a factor that might have affected the Upper Runde sub-catchment sediment yield over time, although there was a lack of empirical information to substantiate this claim. However, the current study addresses

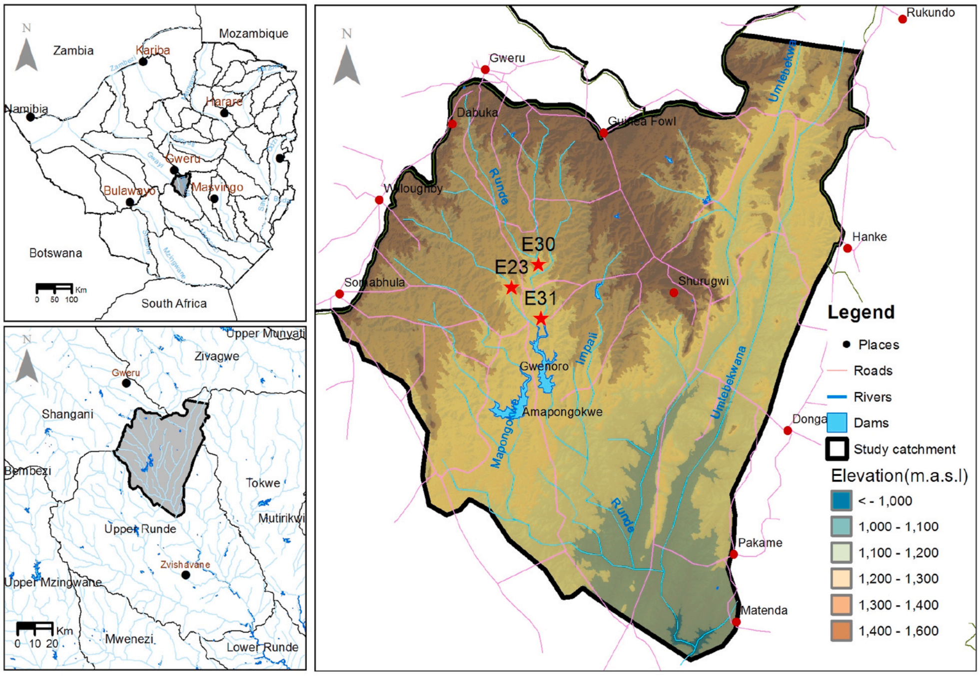

Fig. 1. Location of Gwenhoro dam in the Upper Runde Sub-catchment area, Zimbabwe.

Table 1
Characteristics of the Landsat images that were used in the LULC classification.

Parameters	2000	2016
Sensor	Landsat ETM+	Landsat OLI
Acquisition Date	August 29, 2000	September 02, 2016
Path	170	170
Row	074	074
Cloud cover	0.0	0.57
Center Latitude	20°13′48"S	20°13′47.86"S
Center Longitude	29°51′11.16"E	29°53′06.68"E
Sun Elevation angle	46.57098848	49.52009421
Sun Azimuth angle	50.40719805	49.29651137

the gap. Shuttle Radar Topography Mission (SRTM) DEM at 30 m resolution was obtained from Earth Explorer website (http://usgs.earthexplorer.com). The erodibility factor was obtained from the soil map of Zimbabwe that was downloaded from the website (www.fao.org/geonetwork).

2.2.2. Classification method

Landsat images for the years 2000 and 2016 were used to detect land use and land cover changes for the Upper Runde sub-catchment. Supervised classification of multi-temporal images was done using the Random Forest (RF) algorithm. This is an ensemble machine learning algorithm based on decision trees that developed by Breiman (2001) to solve classification problems. RF employs an iterative bagging operation where a number of trees (*ntree*) are independently built using a random subset of samples from the training samples provided from the subset of images. The tree are then independently grown and pruned to a maximum size based on a bootstrap sample while each node is then split using the best, among a subset of input variables (*mtry*) (Breiman and Cutler, 2007; Chemura and Mutanga, 2016). This algorithm is very efficient in processing time, accurate and also able to handle highly non-linear data, robustness to noise and tuning simplicity. The default number of trees (*ntree*) of 500 was used while *mtry* was determined as the square root of the total number of variables used. The r package randoForest was used for running the RF modelling (Liaw et al., 2009) while associated packages such as caret and raster were used in the classification. Five classes were used in the classification scheme and these were water, Built/Bare/Fallow, Grassland, Woodland and Forest. These are described in detail in Supplementary materials.

2.7. Classification accuracy assessment

From the samples for 2000 and 2016, 60% of the data was used for training while the remaining 40% was used for accuracy assessment of the classification using a confusion matrix. The overall accuracy (OA), kappa and multi-class area under receiver operating curve (AUC) were used to determine overall classification performance while user's accuracy (UA), producer's accuracy (PA) were used for class-specific accuracy (Liu et al., 2007; Chemura et al., 2020).

2.3. Soil erosion estimation

2.3.1. Field data

A hybrid of quantitative and qualitative data were employed to investigate the Upper Runde sub-catchment sediment concentration and annual yield in order to assess the sedimentation risk of the Gwenhoro dam. Sediment load was measured at three stations (E23, E30, and E31, Fig. 1) upstream of the Gwenhoro reservoir between December 2016 and April 2017, which falls within the rain season. Sampling was done using the scooping method (Ongley 1996). Samples were collected in 500 ml containers at a minimum depth of 300 mm below the water surface and sent to ZINWA for analysis. The filtration and weighing method were used to analyse the sediment load from the three stations. This was done to get the current sediment concentration instead of relying on simulation results only, considering that Gwenhoro catchment does not have ZINWA sediment sampling points. ZINWA has not measured sediment concentration upstream of the Gwenhoro dam and depend on sediment concentration categories designed by the Zimbabwe Institute of Engineers (2010) for decision making in catchment management (Table 2). The study area was categorised under the generic 3000 mg/l (Table 2).

2.3.2. Determining RUSLE factors

The revised Universal Soil Loss Equation (RUSLE) model requires a

Table 2
Sediment concentration categories.

Catchment description	Sediment concentration
Catchments with well-developed conservation measures and moderate topography	3000 mg/l
Catchments with poor conservation measures, prone to erosion and steeper slopes	5000 mg/l
Catchment highly susceptible to erosion	10 000 mg/l

Source: Zimbabwe Institute of Engineers (2010)

number of factors to be determined for estimating soil loss. Normalized Difference Vegetation Indices (NDVI) were extracted from the Landsat series data used for the classification, and this was used to calculate the land cover and crop factor (C factor (Fig. 2a and b)), using the formula developed by Renard (1997) and tested and recommended for African settings (Marondedze and Schütt, 2020) as well as in other regions (Rawat and Singh, 2018; Maliqi and Singh, 2019; Kumar Pradhan et al., 2020). Digital Elevation Model (DEM) was used to calculate the slope length and slope steepness factor (LS factor, (Fig. 2c). The K factor was calculated from soil texture, soil organic composition from the ISRIC Africa Soil grids and Zimbabwe soil type map. It shows the integrated effects of rainfall, runoff, and infiltration on soil loss, accounting for the influences of soil properties on soil loss during storm events on upland areas (Fig. 2d). The average rainfall data for the period between 2000 and 2016 were obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) daily data at 0.05° resolution (Funk et al., 2015) and used to determine the R factor (Fig. 2e). Management Practice (P factor) represents how surface and management practices are used to reduce soil erosion. Where there is no support practice, 1 is assigned for P factor, and those areas with well-developed land conservation practice, the factor is 0 (Wordofa 2011).

2.3.3. *Soil loss estimation with RUSLE*

The RUSLE was then used to simulate sediment yield for the Upper Runde sub-catchment in a GIS system to assess the risk of sedimentation for the Gwenhoro reservoir. Modelling is one of the approaches for estimating catchment soil loss and sediment yields (Ndomba 2013). Soil erosion and sediment transport are a function of many processes and factors that include slope, soil erodibility, runoff erosivity, and management practice. The influence of these factors on soil erosion by water in the Upper Runde sub-catchment was assessed using the RUSLE equation (Renard 1997) as follows:

$$A = R* K* SL*C* P \qquad [1]$$

Where: A = annual soil loss, R = rain erosivity factor, K = soil erodibility factor, SL = slope steepness and slope length, C = land cover and crop management and P = management practice.

RUSLE model is not immune to weaknesses. The result from the RUSLE model shows the average soil loss from the catchment. In other words, the estimated soil loss should not be interpreted as sediment contribution to a river flow system since it does not account for deposition that occurs in the path (De Vente et al., 2013). Therefore, Sediment Delivery Ratios (SDR) representing the fraction of the total soil loss that is washed into rivers was calculated using (TMDL, 1983) equation:

$$SDR = 0.5656A-0.11 \qquad [2]$$

Where: SDR = Sediment Delivery Ratio and A = watershed, km^2

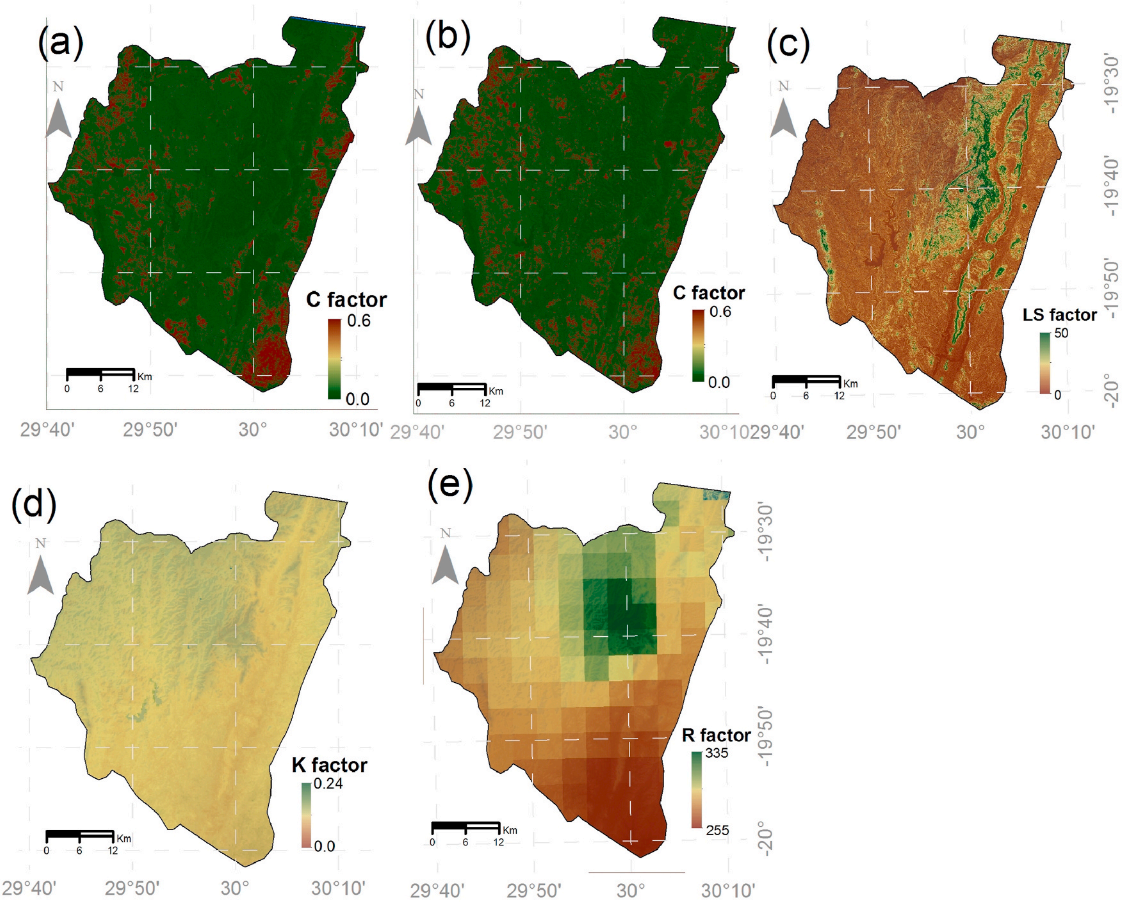

Fig. 2. Spatial distribution of factors of RUSLE model (a) C factor for 2000, (b) C factor for 2016, (c) LS factor. K factor and (e) R factor. The DEM is shown in the study area map and the landuse factors were from the image classification.

After determination of the Sediment Delivery Ratio, the average sediment yield was determined using the formula developed by Wischmeier and David Smith (1978):

$$SR = SDR*A \qquad [3]$$

Where: SR = Sediment yield, SDR = Sediment delivery ratio and A = Average soil loss.

2.4. Key informant interviews

Qualitative data obtained from key informants and selected farmers and artisanal miners on land-use changes, soil conservation, and management practices were analysed using content analysis method (Krippendorff 2012). Semi-structured interviews, guided by a template with a set of general questions, were used to collect data on the causes of changes in the catchment's biophysical conditions. The interviewees were key informants purposely selected from the Ministry of Land, Agriculture and Rural Resettlement, Agricultural, Technical and Extension Services (Agritex), Environmental Management Agency (EMA), Upper Runde Sub-catchment Council and ZINWA. The District Land Officer was selected from the Ministry of Lands, Agriculture and Rural Resettlement to explain changes in the existing tenure and possibly land use.

The District EMA Officer was included because of the agency's mandate to protect the environment in Zimbabwe. Agritex Officer was chosen on the basis that the organization is responsible for advising farmers on suitable farming methods and monitoring their conservation measures. Upper Runde Sub-catchment Council Officer was selected because the institution is responsible for catchment management, and the Hydrologist was selected from ZINWA because the institution oversees water resources distribution and management. Four artisanal gold miners conveniently selected during fieldwork were also interviewed together with ten purposely selected farmers located in different parts of the catchment to compare views from other parts of the sub-catchment area.

3. Results

3.1. Accuracy assessment of land cover classification

The accuracy assessments of the image classification process are shown in Fig. 3. The results indicate the classification for 2016 was much better than the classification for 2000 as the overall accuracy, kappa and AUC were higher for the former in all cases. For the 2000 classification the class water had the best users and producers accuracies (0.93 and 0.98 respectively) while the least was woodland (0.62 and 0.88) for users and producers accuracies respectively). The classes water and cropland/bare/built-up has perfect classification in the 2016 classifications (Supplementary materials). The overall performance of the classification was satisfactory as the balanced accuracy and multi-class AUC was higher than 0.75 for all classes and thus the classified images could be used with confidence for the land cover change assessment and as factors in the soil loss estimation.

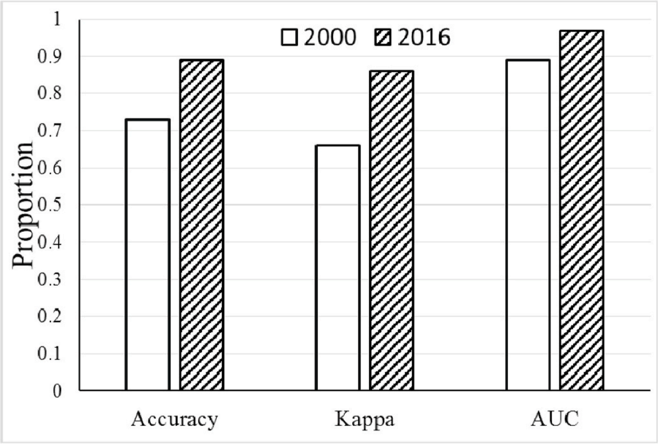

Fig. 3. Accuracy measures for the 200 and 21016 land cover classifications as proportions.

3.2. Land cover change analysis

The classified maps for 2000 and 2016 are shown in Fig. 4. For both periods the central areas are covered by forest areas as they are part of the Great Dyke of Zimbabwe, with communal areas to the east and farming areas to the west. The statistical results of land cover and land-use change for various categories are presented in Fig. 4 to show the trends of change in percentages. Image classification results show that the sub-catchment is predominantly covered by grasslands which covered 49% (1044 km^2) of the area in the year 2000 (Fig. 4). This is followed by woodland at 25% (532 km^2) of the sub-catchment and water being the least with 0.9% (19.5 km2), majority being the Gwenhoro and Amapungukwe dams.

Percentage changes show significant differences in all the other classes except the area covered with water (Fig. 5), which slightly increased by 0.1%–1% by 2016. Many LULC dynamics occurred between 2000 and 2016 which are captured by the Sankey plot. The class cropland/bare/built-up increased by 16% from its original area in 2000 with this increase coming from transitions from mostly grasslands, but also from woodlands and forests. Some of the areas that were classified as cropland/bare/built-up transitioned to grassland class by 2016. 16% of grassland in 2000 was converted to cropland/bare/built-up of woodlands had become grasslands, losing trees and other tree cover (Fig. 5). Forests and woodlands areas decreased by 39% and 23% respectively between 2000 and 2016. Although the grassland class remained the dominant class in the catchment by 2016, it was the class with the biggest changes by area in the catchment. Overall, the results show that forests, grassland decreased while cropland/bare/built-up, water and woodland classes increased between 2000 and 2016.

3.3. Soil loss, sediment load and sediment yield

The modelled soil loss per ha per year for the year 2000 are shown in Fig. 6a. The soil loss was then categorised into five severity classes (Fig. 6b). The analysis of the severity classes shows that 90% (1896 km^2) of the catchment was in the very low soil loss class while only 0.6% (13 km^2) was in the category very high in 2000 (Fig. 6c). The modelled soil loss per ha per year for 2016 are shown in Fig. 6d with the classes of severity in Fig. 6e. Compared to the year 2000, the very low and low soil loss categories decreased by 4.45 and 0.3% respectively while the high and very high soil loss areas increased by 1.7% and 2.5% respectively (Fig. 6e). The areas with very high soil losses are distributed across the sub-catchment but appear to be concentrated on the southern and eastern parts in 2000 (Fig. 6b) but extend to the central, western and northern parts of the catchment by 2016 (Fig. 6e).

The average sediment concentration for stations E23, E30, and E31 for the period between December 2016 and April 2017 was 6272 mg/l. This represents a change from the expected maximum of 3000 mg/l used by the sub-catchment council to manage soil erosion in the Upper Runde sub-catchment area. RUSLE soil loss simulation results show an increase in average soil loss from 1.2 ton/ha/yr. in 2000 to 1.7 ton/ha/yr. in 2016. It was observed that the highest sediment yield is coming from the eastern side of the catchment area due to the proliferation of illegal gold miners (Fig. 6e). The SDR values which shows the total soil loss that is washed into rivers for 2000 was estimated at 3196 mg/l and increased to 3213 mg/l in 2016. The sediment yield increased by 19.2% from 3476 mg/l in 2000–4144 mg/l in 2016, indicating that more sediment were

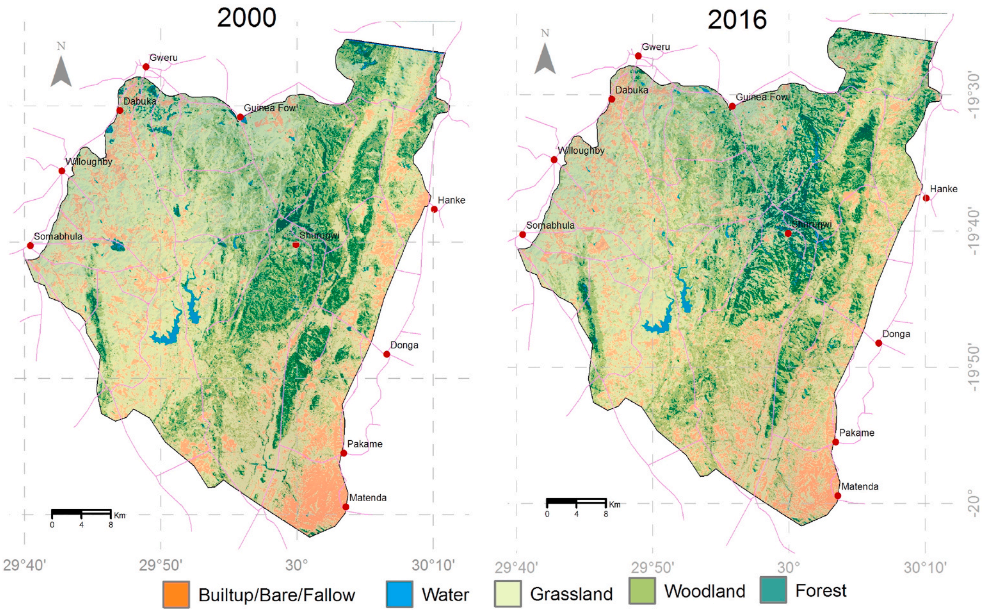

Fig. 4. Maps showing the distribution of the land cover types in Upper Runde study area for (a) 2000 and (b) 2016.

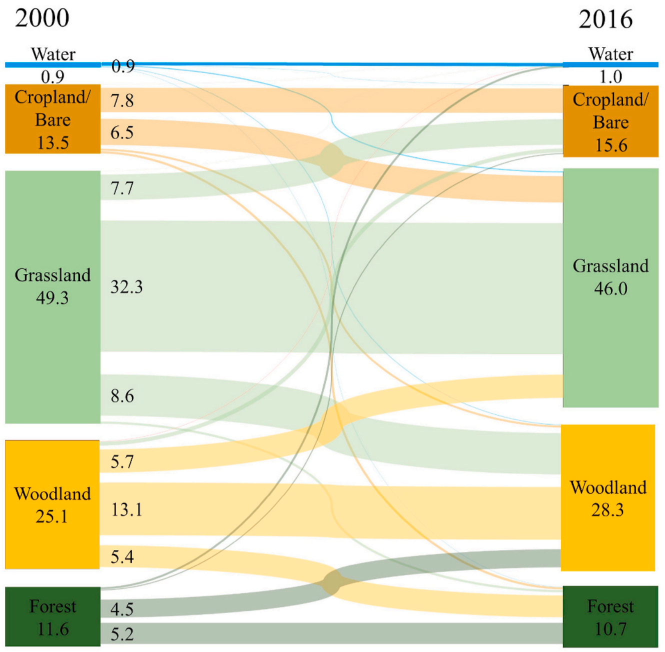

Fig. 5. Percent are transitions between the 2000 and 2016 land cover classes in the catchment. The values are percentages of the overall study area size.

being driven into the rivers from the catchment. The sediment yield change between 2000 and 2016 appears to correspond with land use and land cover dynamics in the sub-catchment where most of the land has been transformed from forests and grasslands to croplands and bare areas.

3.4. Causes of the degradation in Upper Runde sub-catchment

Interviews with the Agritex, EMA, and the Sub-catchment council officers suggested that the increase in cropland and bare area and a concomitant decrease in forest and woodlands is linked to the clearance of more land for crop farming in the aftermath of the FTLR programme. The Ministry of Land and resettlement key informant revealed that from 2000, small- and large-scale farmers have been utilising the land without observing soil conservation practices. The land reform programme also introduced land subdivisions to accommodate more new subsistence and commercial farmers in a catchment area that was previously dominated by commercial livestock farming. The finding may explain the susceptibility of the catchment to soil loss, which in the process increases the risk of reservoir sedimentation given the 1.2 ton/ha/yr. in 2000 to 1.7 ton/ha/yr. in 2016 RUSLE results.

Interview responses from the randomly selected small-scale gold miners revealed that unregulated mining activities were common in the catchment. All the interviewed farmers indicated that the area was invaded by external illegal miners who had no regard for land conservation. In some instances, open mining pits were abandoned and left for farmers to reclaim. The Environmental Management officer confirmed that the nature of mining and farming in the area was characterised by veld fires, vegetation clearance, and land degradation. The Hydrologist also concurred with the EMA officer and emphasized that the streams and rivers in the area were at risk of siltation because of the bare land and disturbed soil catena. Interviewed miners and farmers had no environmental management plans for environmentally-friendly mining activities. Sixty-eight percent of farmers indicated that they were practicing farming without conservation measures because of the uncertainty associated with land tenure security given the background that only 80% of them had no lease agreements or title deeds. The findings from interviews with the farmers showed a lack of environmental stewardship.

According to ZINWA, suitable conservation methods used to be in place before land reform. However, change of land use with the coming in of new subsistence farmers and inadequate agricultural extension service undermines effective management of the landscape, a position supported by EMA and Agritex officers. Agriculture extension officers rarely visit farmers for training and capacity building due to a shortage of the necessary resources. However, some key informants associated the lack of proper management of the catchment area with poor enforcement of the law due to political interference.

4. Discussion

The aim of this study was to use the empirical RUSLE model to determine the influence of LULC in Upper Runde sub catchment on soil loss and sediment loss, important parameters for sustainable watershed

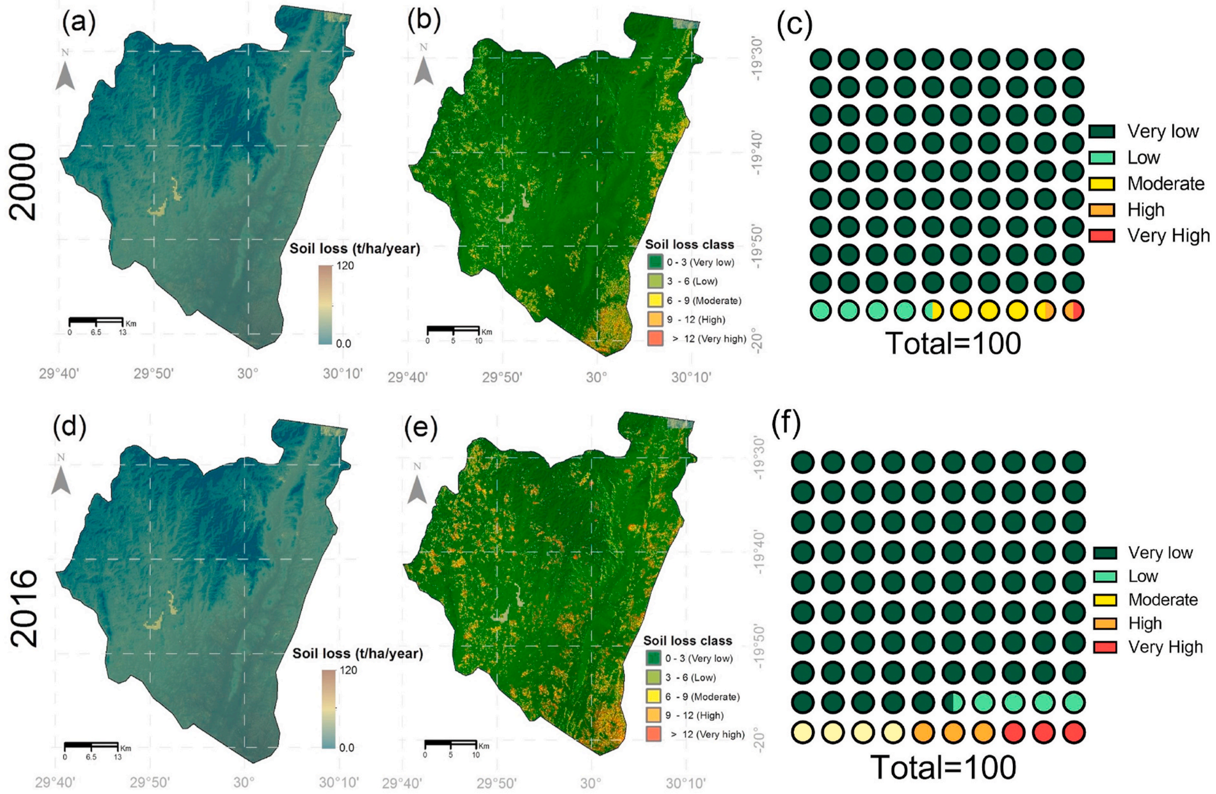

Fig. 6. Soil loss estimation for the Upper Runde showing the (a) modelled soil loss in 2000, (b) soil loss categories in 2000, (c) proportion of categories in 2000, (d) modelled soil loss in 2016, (e) soil loss categories in 2016 and (f) proportion of categories in 2016.

management and reservoir operations. A land cover classification was performed and then the land cover classes used in the RUSLE model with other factors and soil loss, sediment delivery ratio and sediment yield calculated.

The image classification process with the random forest and Landsat imagery produced satisfactory accuracy for the catchment. This is not entirely unexpected considering that the random forest classifier is regarded as one of the most robust remote sensing classifiers currently in use. This good performance is primarily because of its ability to handle non-parametric distribution of data (Breiman and Cutler, 2007), a situation that is prevalent in remote sensing data pixel values. However, there were observed differences in the accuracy performance of the 2016 Landsat OLI and the 2000 Landsat ETM+, with the former having consistently higher accuracies than the latter. These results are explained by two reasons. First, the 2016 training samples are more reliable as they include those from field work and are more representative compared to those of 2000 that were based on secondary data sources. Secondly, and most importantly, according to Dube and Mutanga (2015), the newer Landsat 8 OLI sensor is an improvement from its predecessors in that it has a refined spectral range for certain bands that is critical for improving the vegetation spectral responses, it has improved radiometric resolution from 8 bits to 12 bits and that it has better signal to noise ratio that is almost twice as good as Landsat 7 ETM+. Given these explanations, the better performance of the 2016 classification are not entirely surprising.

The rate of land use and land cover change was assessed and further used to establish whether the observed changes can be linked to sediment load and annual sediment yield within the Upper Runde sub-catchment area. The findings of the study have shown that the amount of sediment yield from the Upper Runde sub-catchment area has increased over the period from 2000 to 2016, a period that coincides not only with the inception of the FTLR programme but other land based programmes. The changes can be attributed to the FTLR, but more research is still required to ascertain the contribution of different sectors such as mining and urbanisation to the changes in the catchment. Some literature shows that before the FTLR programme large-scale commercial farmers involved in livestock production maintained optimal livestock numbers to avoid overgrazing; hence soil erosion was controlled (Whitlow 1989; Scoones 1992). A change in land use accompanies the FTLR programme, and land cover characterised by the transformation of forests, woodlands, and grasslands into croplands and bare areas, something that is also observed in our results. The increasing spatial extent of the bare area could have been influencing high sediment load (6272 mg/l) measured at three stations (E23, 30, and 31). The measured sediment represents a change from the expected maximum sediment load 3000 mg/l, as per sediment classification by (Zimbabwe Institute of Engineers, 2010), used by the catchment councils to manage soil erosion in Zimbabwe. According to Mavima et al., (2010); Mutowo and Chikodzi (2013), a catchment area that has a sediment load above 5000 mg/l is prone to soil erosion and higher sediment yield. This appears to be true for the Upper Runde sub-catchment area recording an average of 6272 mg/l sediment load, an indicator of enhanced soil erosion linked to massive degradation.

The changing land cover and land use characteristics created conditions ideal for enhanced soil erosion in the Upper Runde sub-catchment area. The increased sediment yield poses water security threats for the City of Gweru and other surrounding communities that rely on the Gwenhoro dam. Annandale and George (2006) noted that reservoir sedimentation impact on water supply is obvious if no remedial measures are instituted. Lack of regular measurement and inadequate monitoring of catchment erosion, increasing sediment loss, is likely to enhance sedimentation of the Gwenhoro reservoir. These results concur with those of Mavima et al. (2010); and Chitata et al. (2014) that revealed sedimentation of small reservoirs in the catchment areas of Zimbabwe dominated by communal areas with inadequate catchment erosion control mechanisms. These findings on insufficient catchment protection further augment those of (Rukuni et al., 2006) that newly resettled farmers continue with their environmentally degrading activities that have been contributing to rapid soil erosion in communal areas. In light of low conservation and lack of involvement of the local farmers in catchment anti-erosion management activities in the Upper Runde sub-catchment, the alternative way to abate erosion is to institute integrated watershed management involving the participation of the local people, and a strategy also upheld in other empirical studies (Alemu 2016; Chitata et al., 2014).

The introduction of crop farming techniques with inadequate conservation measures, such as the absence of contours and down-slope cultivation on steep gradient, could have accelerated soil erosion. According to Verstraeten et al. (2003), tillage without proper erosion measures on steep slopes accelerates soil loss. Our research findings further concur with those of the Zimbabwe Institute of Engineers (2010) and Chitata et al. (2014) that show that catchments with insufficient conservation measures are more prone to erosion. It was observed that before the FTLR programme large scale commercial farmers involved in livestock production maintained optimal livestock numbers to avoid overgrazing; hence soil erosion was controlled. In contrast, the catchment is now dominated by subsistence crop production with low conservation measures and unregulated artisanal mining. Matsa (2011)'s findings have confirmed that many newly resettled farmers are turning to gold panning to improve their livelihoods.

The existence of artisanal mining without proper environmental management plans has been contributing to deforestation through vegetation clearance, haphazard excavations, and veld fires, a situation also confirmed by the Environmental Management Agency (EMA 2014). Terranova et al. (2009), in a study where they modelled water erosion risk under different land uses using GIS and RUSLE, also noted that wildfires in woodlands increase the intensity of erosive processes. Farming and mining activities require proper methods because poor practices make soils highly susceptible to erosion (Mambo and Archer 2007). Therefore, simulations show that some anti-erosive techniques, such as minimum cultivation methods, practices to avoid stubble wildfires, controlled partial grass regeneration, limiting tilling and harrowing as well as increasing areas with vegetation cover cause notable reductions in erosion rates (Terranova et al., 2009), and this may explain why the Upper Runde sub-catchment where all these practices are increasing has been experiencing more soil erosion.

Strategies for managing reservoirs sedimentation may include storing clean water, releasing turbid water, drawdown flushing and empty flushing and dredging Wang and Chunhong (2009). Wang et al. (2005) note that reservoirs further upstream, as the case with Gwenhoro dam, have a more aggravated sedimentation potential as a result of quantities of coarse material which deposit at the head of the reservoirs. This generalisation does not hold if significant sediment producing areas with highly erodible geologic materials are located in mid-catchment areas. In such cases, reservoirs may also have a correspondingly shorter life span (Graf et al., 2010). This study does not claim that the Upper Runde catchment has the highest sediment load than mid- and Lower Runde, but it attempts to assess an area-specific situation (Gwenhoro dam).

5. Conclusion

The study assesses land use/land cover change in the Upper Runde sub-catchment and the potential sedimentation of Gwenhoro reservoir. Findings revealed an increase in sediment load and annual sediment yield as a result of changes in land use/land cover in the area. Land use shifted from predominantly large-scale livestock farming to mixed small scale cropping and livestock production and unregulated artisanal mining, all without proper anti-erosion measures. Conservation practices in the catchment need improvement, particularly in farming and mining activities. The study findings have shown that the catchment is now exposed to high sediment yield; hence monitoring of sediment yield in the catchment should be a priority considering that the last survey done in 1985 show high levels of siltation though lower than currently experienced. Gwenhoro dam is, therefore, at increased risk of sedimentation and 'fill ' up.'

An actual reservoir bathymetry survey is recommended considering that the findings of this study only show a probability of the reservoir sedimentation through inferences. The reservoir is located in the Upper Runde catchment. Therefore, regular sediment monitoring of the Gwenhoro reservoir catchment would be prudent because the dam could be serving as a sediment trap for reservoirs downstream. Gwenhoro is the primary source of water for the city of Gweru; therefore, national dam surveys cannot afford to ignore a water source of such significance as it has a bearing on the water security of the country's third largest city. Finances should be injected through the Catchment Councils, Zimbabwe National Water Authority, local authorities, or institutions of higher learning to conduct further researches that inform policy and proper management of catchment areas.

Declaration of competing interest

Please note that all the authors listed have **no** competing interests to declare.

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Appendix A. Supplementary data

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