ASSESSING LAND USE AND LAND COVER CHANGES IN THE CHEPKOILEL/SERGOIT RIVER CATCHMENT

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Abstract

Land cover refers to what is on the land, natural or man-made, while land use refers to human activities on land. Therefore, there is always a direct link between land cover and the actions of people in their environment. Land Cover and Land Use (LC/LU) changes involves intensification of an existing use, or a shift to a different use. Increasing demand for space for settlement and all types of development are the driving force. The study aimed to quantify the changes in LC/LU in the catchment during the period 1995 to 2020 and to examine their effects on the long term availability of potable water. Medium (Landsat 5) and high (Landsat 8 OLI and Sentinel-2) resolution satellite images of three dates were used and all the data processing and analysis was done in ArcGIS environment. Results showed that the catchment had lost 69% of its forest cover, while farmland increased by 44%; settlement in the catchment increased by 261% and wetland declined by 64% during the period. The upper zone, the main source of the water supply in the catchment, lost 46% of its forest cover during the period. We recommend that immediate steps be taken to increase forest/vegetation cover and implement land conservation in the catchment, especially the upper zone.

Key words: land cover/land use change, water availability, water catchment conservation

Introduction

Land cover refers to what is on the land, natural or man-made, while land use refers to anthropogenic activities on land. Thus, there is always a direct link between land cover and the actions of people in their environment. As stated by Ankana (2016) Land Cover and Land Use (LC/LU) changes involve either a shifting to a different land use or an intensification of an existing one. Increasing demand for space for settlement, agricultural investment and industrial activities across the world is currently being observed (Lambin and Meyfroidt, 2011); Cotula, 2015). This has led to unprecedented land-use and land-cover changes which have caused socioeconomic and environmental problems (Braimoh and Osaki, 2010). Many communities, particularly in developing countries, depend heavily on exploitation of the natural resources for their livelihood (Maithya *et al*., 2015**)**. As a result, human use of land has had and continues to have a profound effect upon the natural environment. The effects have, over time, resulted in observable patterns in land-cover/land-use (Tiwari and Saxena, 2011, Odenyo and Pettry, 1977). As noted, Gilani *et. al.* (2014), Land cover and Land Use changes are among the most important and easily detectable indicators of change in ecosystem and livelihood support systems.

This study examined the land use and land cover changes in the river Chepkoilel/Sergoit over the period 1995 to 2020 as a component of assessment of availability of potable water in the catchment. The river's catchment encompasses an agriculturally productive zone of Uasin Gishu County and includes the northern reaches of Eldoret municipality which has experienced tremendous expansion over the 25 years studied.

Materials and Methods

Materials

Study area

The study area traverses parts of three Kenya counties, that is, Elgeyo Marakwet County in the upper catchment, Uasin Gishu County in the mid and lower catchments and Kakamega County in the lower catchment. It is bounded by Latitudes 00°27' 30''N and 00°42'30''N and Longitudes 35°05'00''E and 35°32'30''E with elevation ranging from 2600m-2131m-1780m in the upper, mid and lower catchments respectively (Figure 9). The catchment receives an average rainfall of between 625 mm to 1,560 mm, with two distinct peaks between March and June, August and September.

The geology of the catchment is dominated by upper Uasin Gishu phonolite in the upper and mid catchment, lower Uasin Gishu phonolite with some spots of gneissose and banded microcline augen in the lower catchment (Figure 10).

The dominant soil type in the catchment is Orthic Ferralsols (Fo) covering mid and parts of upper and lower catchments; Humic Nitosols (Nh) covering parts of upper and lower catchments and Lithosols (l) conversing part of upper catchment (Figure 10).

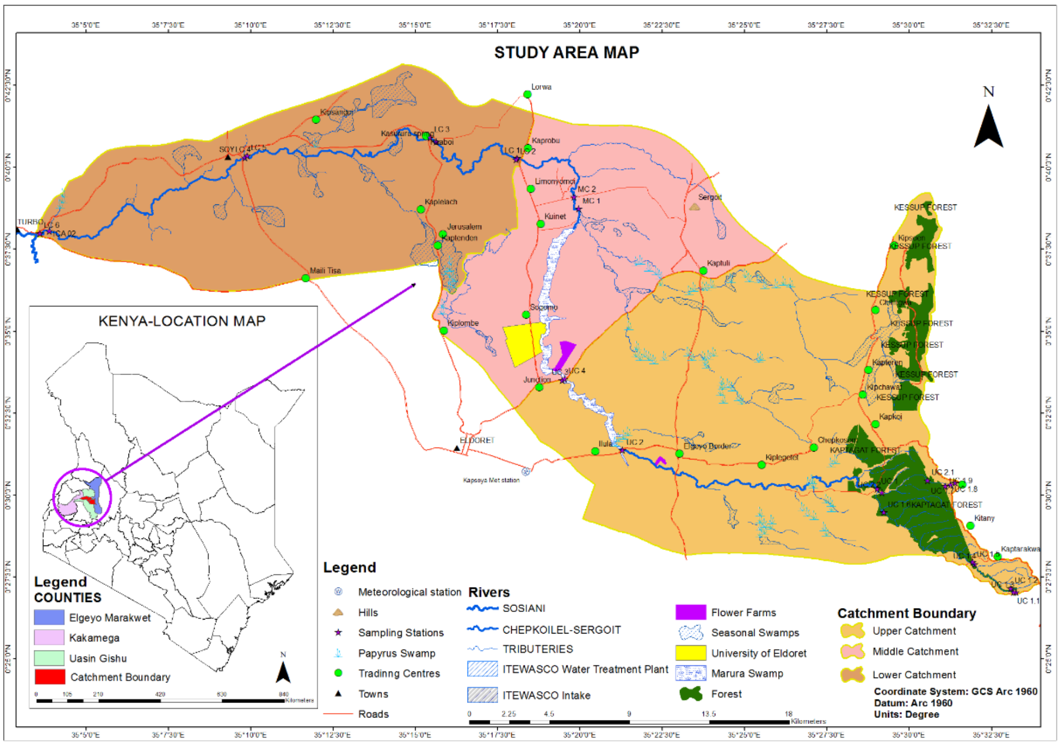


Fig 8: Location of the study area

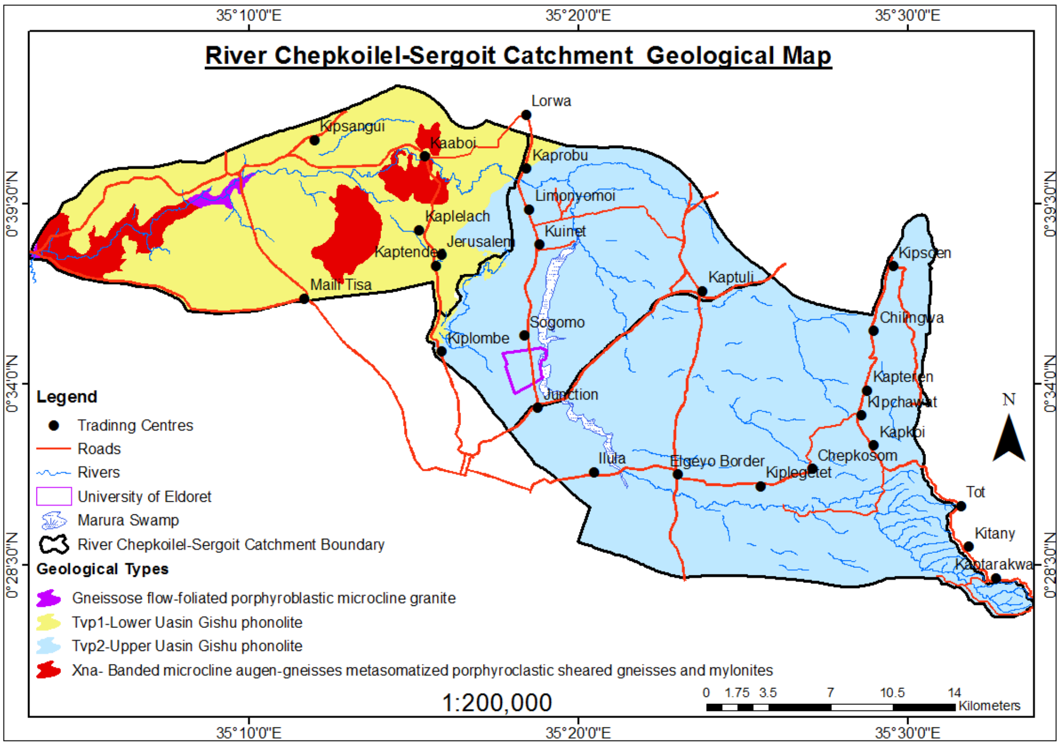


Figure 9: Geological map of the study area

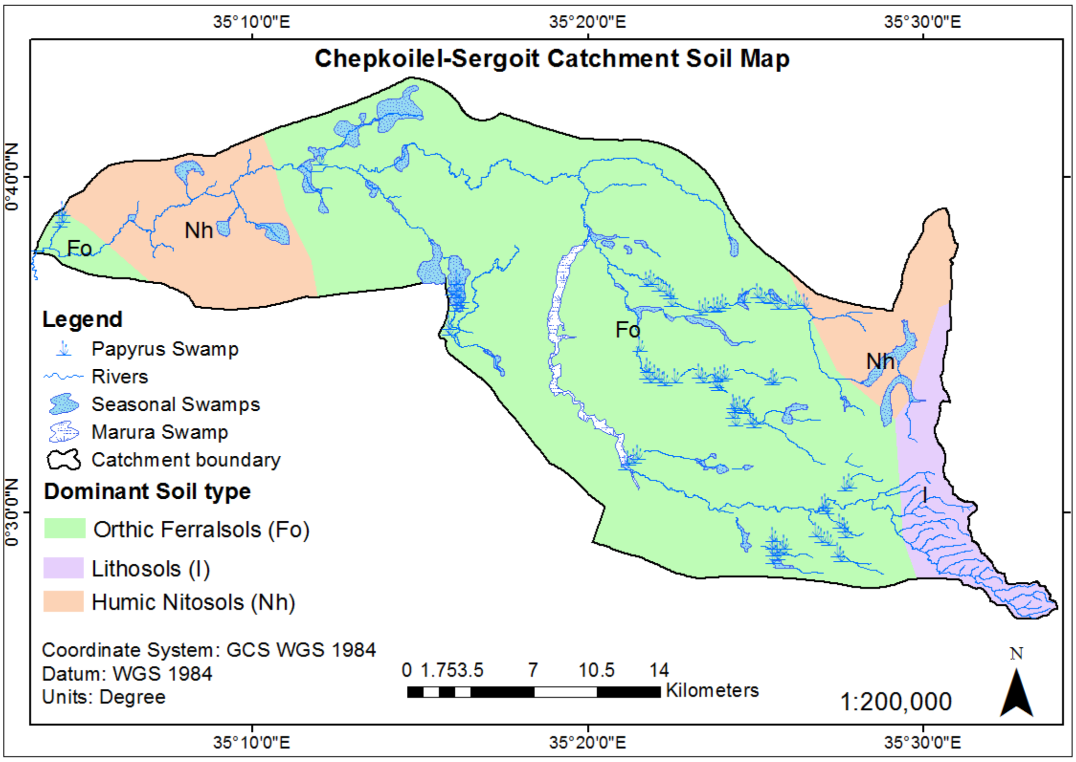


Fig. 10: Soil map of the study area

Datasets used

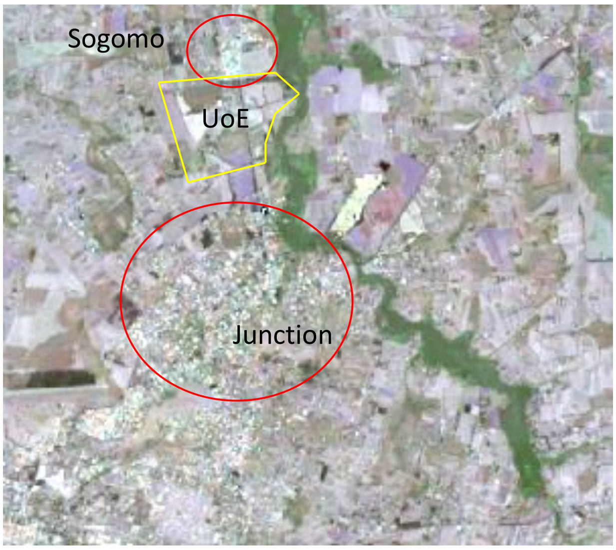
The data used in this study are as shown in Table 1.

Table 1: Datasets used in the study

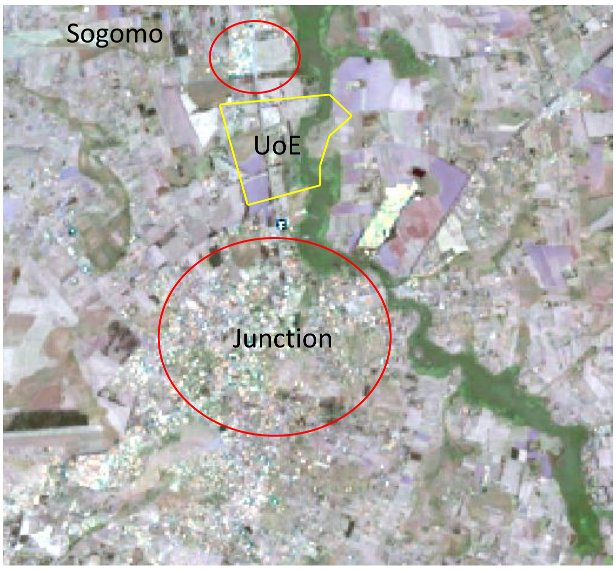
S/No.	*Type of data used*	*Scale/ Resolution*	*WRS_path/row, Granules/Tiles*	*Date of acquisition*	*Source*
1.	Landsat 5 TM image	30m	169/060 and **170**/060	26th Jan. 1995 and 2nd Jan.1995	United States Geological Surveys website (USGS, https://earthexplorer.usgs.gov/).
2.	Landsat 8 OLI-image	30m and 15m	170/059 169/060	22nd Jan. 2014 and 2nd Jan. 2014	United States Geological Surveys website (USGS, https://earthexplorer.usgs.gov/).

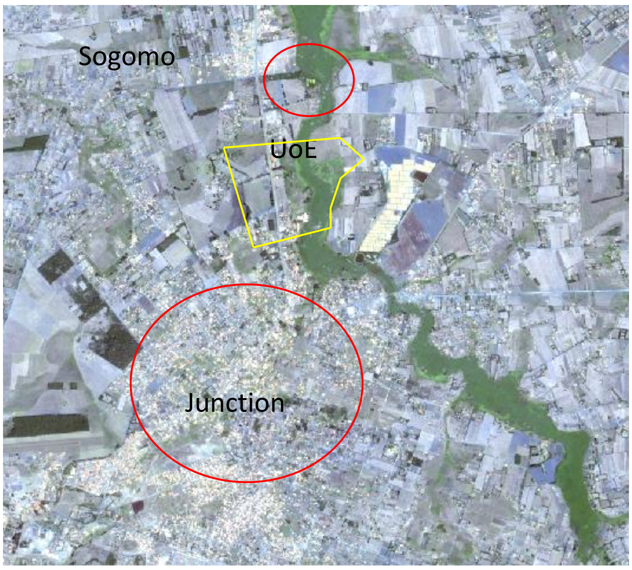
3.	Sentinel-2 image	10m	T36NYF-100×100km	22nd Jan. 2020	United States Geological Surveys website (USGS, https://earthexplorer.usgs.gov/).
4.	Shapefile of study areas	1:50000			Digitized from topographical maps 89/3-Soy, 89/4-Eldoret, 90/3-Tambach, 103/2-Kaptagat and 104/1-Kipkabus all from Survey of Kenya.

All the images used in this study were taken during the dry season (January) in the study area since discrimination of land cover classes is more accurate than images taken during the rainy season (March-September).



(a)





(b) (c)

Figures 11(a), 11(b) and 11(c), showing physical growth of settlements in 1995, 2014 and 2020 images respectively of a section of mid catchment along Marura swamp partially fueled by the presence of University of Eldoret (UoE).

Methods

Image preprocessing

Pan sharpening was done on a composite image of Landsat 8 at 30m spatial resolution using its panchromatic band 8 at 15m spatial resolution in order to improve its cell size to 15m. Image processing was carried out in ArcGIS.

Layer stacking was done as follows: four individual monochrome bands i.e. band 1-blue, band 2-green, band 3-red and band 4- NIR all at 30m spatial resolution for Landsat 5 (1995); five bands i.e. band 2-blue, band 3-green, band 4-red, band 5-NIR at 30m spatial resolution and band 8-panchromatic for Landsat 8 at 15m spatial resolution (2014) and four bands i.e. 2- blue, band 3-green, band 4 - red, band 8-NIR for Sentinel-2 satellite image (2020) were layer stacked in order to produce three composite images.

Image sub setting was done using the shape file of the study area prepared as mentioned above to subset the three images (1995, 2014 and 2020) in order to limit and fit them to the study area.

Image mosaicking was done on Landsat 5 and 8 images of 1995 and 2014 respectively since none of their single path-row covered the whole study area, (i.e. WRS-path-row 169060 and 170060 for Landsat 5 and 170059 and 169060 for Landsat 8). The Sentinel-2 (T36NYF) satellite image was not mosaicked since it covered the whole of the study area.

Land cover classification scheme

From a reconnaissance survey, a total of five main Land cover/Land use classes i.e. farmland, forest, settlement, wetland/swamp and water, were identified, based on modified Anderson et. al. (1976) LU/LC classification system. These were used in the research in generating signature files for the final LU/LC classification. The used LU/LC content types identified are described in Table 2.

Signature file

Training samples were extracted for each land use type from high resolution google earth image of each of the three years and overlaid on the geometrically corrected image ready for classification to help guide in selecting the signatures for each of the five land-over classes. Ten signatures were created for each class, later merged into a single class. These provided the input samples for supervised classification.

Supervised classification

A supervised maximum likelihood classification (MLC) algorithm was subsequently applied to each image. The basic equation of MLC assumes that these probabilities are equal for all classes, and that the input bands have normal distribution.

Area calculation

After classification, the areas for each individual land cover class were calculated using field calculator geometry in ArcGIS. The algorithm multiplies the field of 'counts' with cell size for each image i.e. 30*30m (Landsat 5), 15*15m for Landsat 8 and 10*10m for Sentinel-2.

Accuracy assessment

Confusion matrix tables for 1995, 2014 and 2020 were created to assess accuracy of classification results. The process produces four metrics: the user's accuracy, producer's accuracy, the overall accuracy and the Kappa statistic (Congalton, 1991a). The Kappa statistic shows the probability that the values presented in the error matrix are significantly different from those from random samples of equal size (Benjamin, 2004).

Classification accuracy was done by comparing two datasets: one based on the analysis of remotely sensed data, and the other based on reference information (Congalton 1991); and a nonparametric kappa test was also used to measure the classification accuracy, as it accounts for all of the elements in the confusion matrix rather than the diagonal elements (Rosenfield and Fitzpatirck-Lins, 1986).

Change detection

Change detection was done by calculating the changes in land cover between two consecutive images. This was done for 1995-2014, 2014-2020 and 1995-2020. Figure 12 summarizes the various steps used in the study.

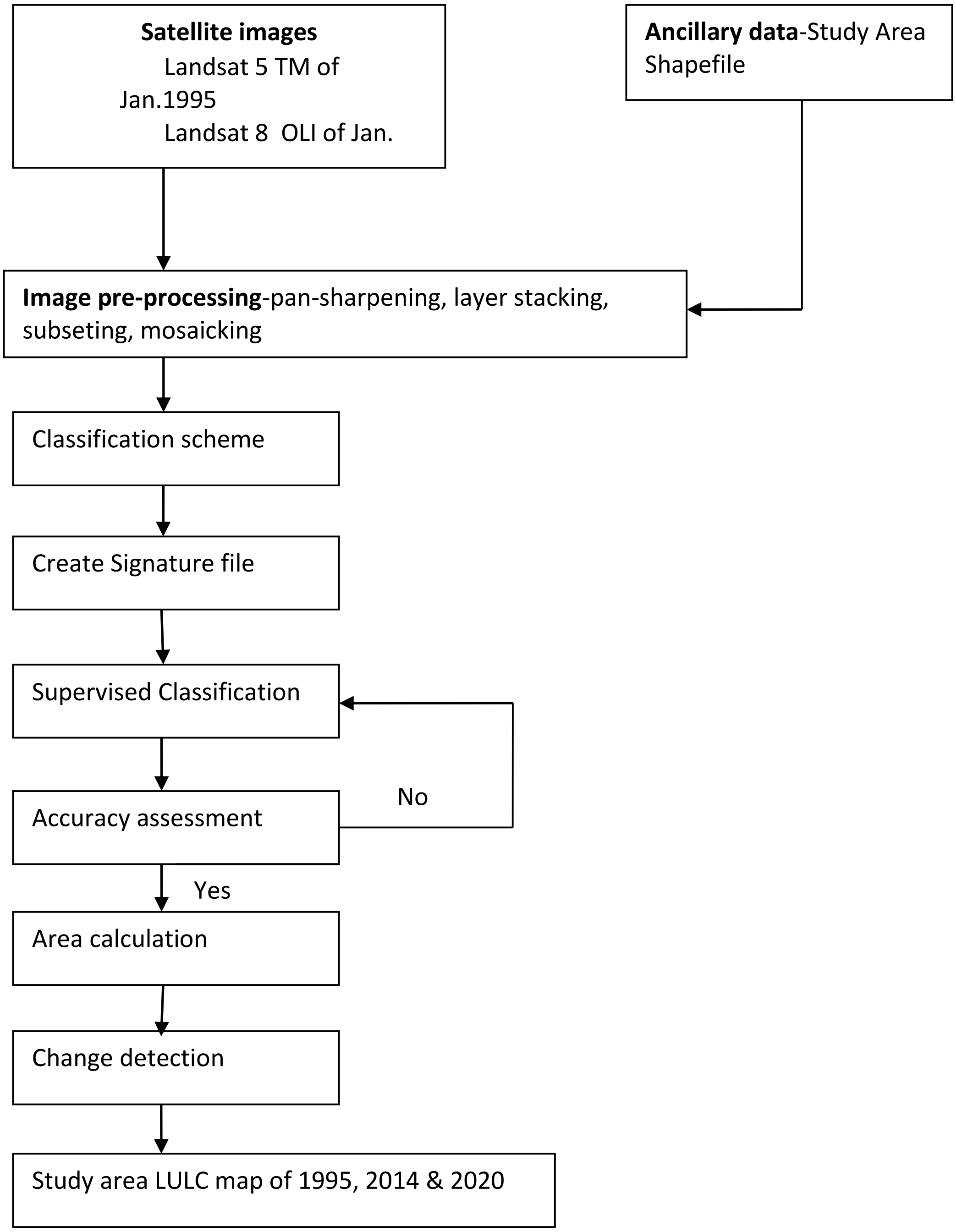
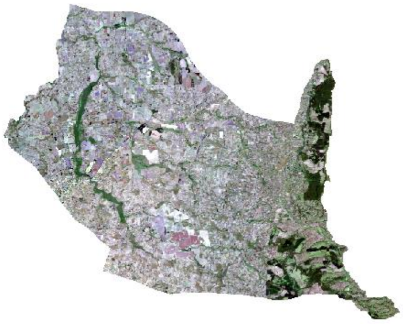


Figure 12: Flow Chart Summarizing Processes Used in the Study

Results and Discussion

Image subsetting and mosaicking

Image subsetting helps limit and fit the images to the study area while mosaicking combines two adjacent composite images to cover the whole study area. Figure 13 shows subset and mosaic image of 2014.



Figures 13: Shows subset and mosaic of mid and upper catchment of Landsat 8 of 2014 image.

Figure 14: Shows subset of 2014 Landsat 8 image with training samples of LULC classes (forest-blue, farmland-yellow, settlement-red, wetland/swamp-cyan).

Signature file

Signature file was created for the LULC classes with five fields (Table 2) of 2014 image i.e. ID, Class Name (indicate name of LULC class), Value (indicating number corresponding to class name), Colour (indicate the colour of training sample) and Count (indicating the number of samples of each class).

Table 2: Training sample manager

Training Sample Manager

ID	Class Name	Value	Color	Count
1	Forest	1		3143
2	Farmland	8		1074
3	Settlement	13		351
4	Swamp	18		324

Land cover classification scheme

The five Land Cover/Land Use classes identified from reconnaissance surveys i.e. farmland, forest, settlement, wetland/swamp and water, are described in Table 3.

Table 3: Land cover classification scheme

No.	Land cover	Description
1.	Farmland	Farms with crops, those under cultivation and those where crops had been harvested
2.	Forest	natural and planted
3.	Settlement	Human constructed structures and other impervious surfaces including rocky surfaces
4.	Wetland/ swamp	Natural
5.	Water	rivers, dams and any surface water

Supervised classification

The resulting Land Cover/Land Use maps for the three periods are presented in Figures 15-17. Notable in the 1995 map are the widespread extent of the forest and wetland/swamp complex cover types in the upper catchment-the headwaters of the river [Figure 17]. These were both forests planted for timber supply and natural forests dominated by indigenous vegetation. Notable also are the very widely scattered settlements in the lower catchment. Settlements in the middle catchment are likely influenced by the suitable topography (gentle slopes) of the Uasin Gishu plateau and proximity to Eldoret town.

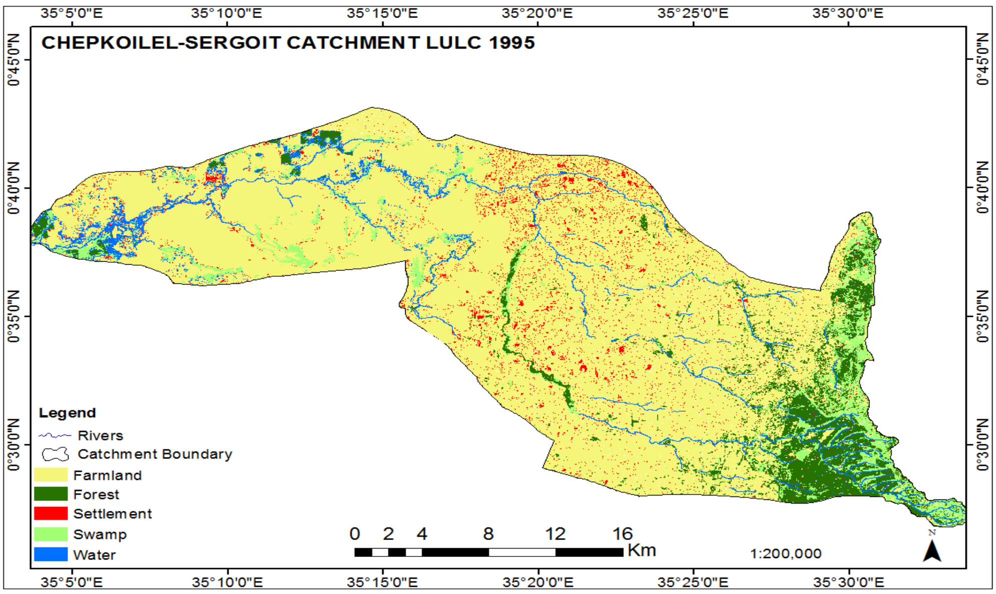


Figure 15: Land Cover/Land Use map of River Chepkoilel-Sergoit catchment in 1995

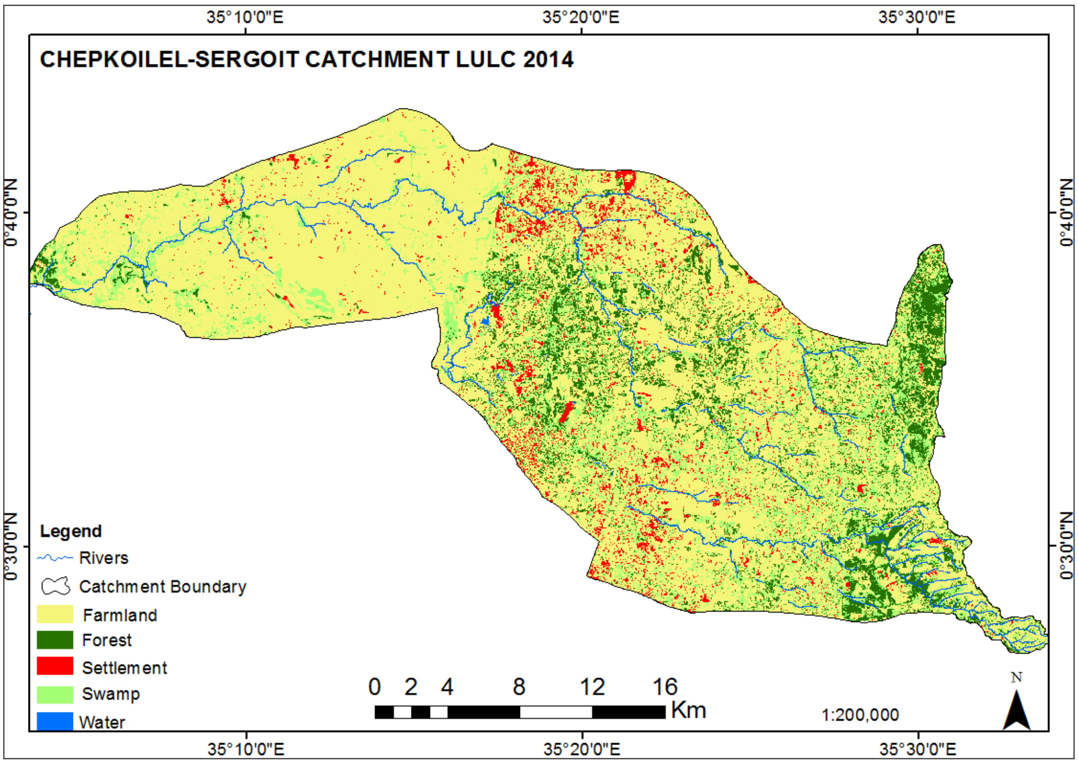


Figure 16: Land Cover/Land Use Map of River Chepkoilel-Sergoit catchment in 2014

By 2014 the forest-wetland/swamp complex had been substantially reduced, especially in the south-eastern corner of the catchment as shown in Figure 6(b). There is more farmland in the upper catchment. The middle catchment shows substantial increase in coverage of settlement areas and the lower catchment exhibits a modest increase also. Scattered patches of planted forest stands and wetlands/swamps (many of them seasonal) in the middle catchment are also well represented.

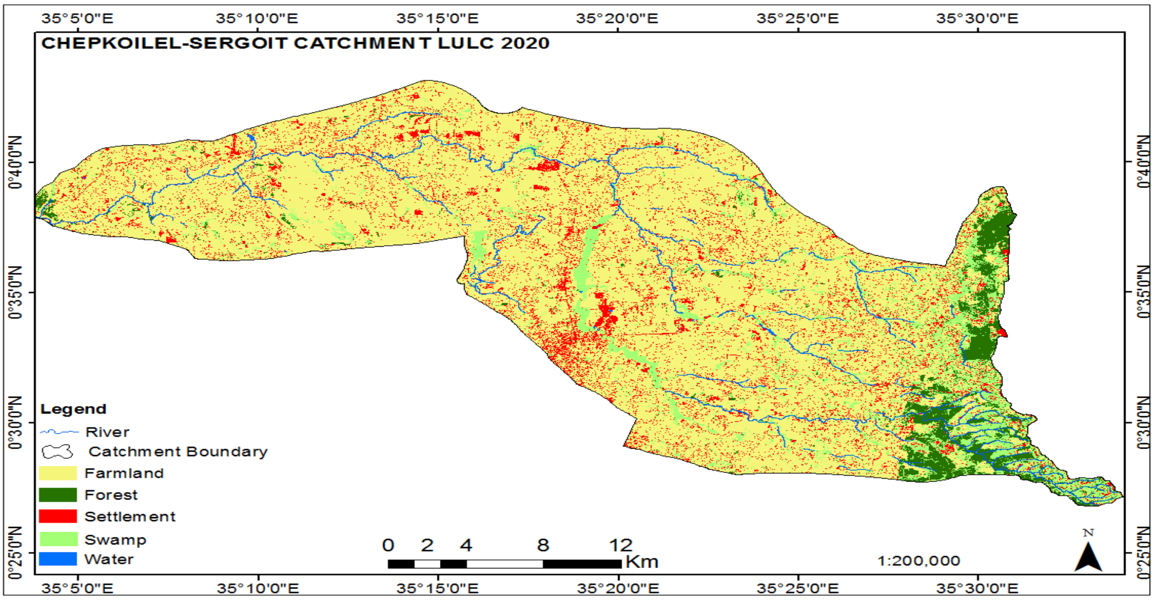


Figure 17: Land Cover/Land Use Map of River Chepkoilel-Sergoit catchment in 2020

In the 2020 map [Figure 17] the most remarkable feature is the extent to which settlement has spread throughout the catchment. High population growth and the impact of the growth of Eldoret town is clearly visible in the growth of settlements in the south-central part of the middle catchment which includes the northern suburbs and peripheries of the town, around the Marula wetland/swamp, and along the transport corridors leading northwards. This is also the location of the University of Eldoret, which has contributed substantially to the growth of settlements. Much of the forest areas in the upper catchment have been converted to farmland (commercial tea estates and other farms) and settlement is widespread throughout the area.

Accuracy assessment

Accuracy defines correctness and it measures the degree of agreement between a standard that is assumed to be correct and a map created from an image (Anand, 2017). A visually interpreted map or classified image is only said to be highly accurate when it corresponds closely with the assumed standard. In the context of image interpretation, accuracy assessment determines the quality of information derived from remotely sensed data.

Accuracy in LCLU classification is normally assessed through the use of three parameters: confusion matrix, kappa coefficient and overall accuracy. The matrix compares the actual target values with those predicted by the machine learning model, and the kappa coefficient is an index to express the accuracy of an image classification used to produce a thematic map **(**Rosenfield and Fitzpatrick-Lins, 1986), and is derived from the confusion matrix. The values of the kappa index vary from -1 to 1, and the closer it is to 1 the more accurate the results are. The overall accuracy, which is the number of correctly classified pixels across all classes, also derives from the confusion matrix.

Tables 4(a), 4(b) and 4(c) below show the confusion matrix and the values of the kappa matrix and overall accuracy for each of the Land Cover/Land Use maps in Figures 15-17. Overall accuracy for the 1995 map was 83.33% with a Kappa coefficient of 0.7916667, that of 2014 was 90.67% with a Kappa coefficient of 0.8833333, and that of 2020 was 92.67% with a Kappa coefficient of 0.9080268. The Kappa coefficients indicated near perfect agreement as per Cohen's (1960) statistics table. All the maps were within the acceptable range of accuracy in mapping with remotely sensed imagery (Anderson *et al,* 1976).

Table 4(a): Confusion Matrix Table for Landsat 5 TM of 1995

Land cover	Farmland	Forest	Settlement	Wetland	Water	Total User's
Farmland	22	4	4	0	0	30
Forest	0	26	2	2	0	30
Settlement	5	0	25	0	0	30
Wetland/swamp	0	6	0	24	0	30
Water	0	2	0	0	28	30
Total Producer's	27	38	31	26	28	150

Overall accuracy = 83.33%, Kappa coefficient = 0.7916667.

Table 4(b): Confusion Matrix Table for Landsat 8 OLI of 2014

Land cover	Farmland	Forest	Settlement	Wetland	Water	Total User's
Farmland	26	2	2	0	0	30
Forest	0	29	0	1	0	30
Settlement	2	1	27	0	0	30
Wetland/swamp	0	4	0	24	2	30
Water	0	0	0	0	30	30
Total Producer's	28	36	29	25	32	150

Overall accuracy = 90.67%, Kappa coefficient = 0.8833333.

Table 4(c): Confusion Matrix Table for Sentinel-2 of 2020

Land cover	Farmland	Forest	Settlement	Wetland	Water	Total User's
Farmland	27	1	2	0	0	30
Forest	0	30	0	0	0	30
Settlement	2	0	28	0	0	30
Wetland/swamp	0	3	0	26	1	30
Water	0	2	0	2	28	30
Total Producer's	29	36	30	28	29	150

Overall accuracy = 92.67%, Kappa coefficient = 0.9080268.

Area calculation

The areas for each individual land cover class were calculated using field calculator geometry in ArcMap. The 'field calculator' multiplies the field of 'counts' with cell size for each image. Since the pixel sizes in each image are known, the area covered by each LC/LU class was expressed in kilometers (Table 5).

Table 5 also shows how the LC/LU has changed in the 25 years covered in the study. It shows that between 1995 and 2020 farmland has increased by 44%, forest cover has reduced by 69%, settlement has increased by 261%, and wetland/swamp has declined by 64%.

Table 5: LC/LU class area coverage (km²)

Land cover	Area km² 1995	Area km² 2014	Area km² 2020
Farmland	368.87526	492.185971	531.975758
Forest	115.17321	78.770101	34.91184
Settlement	20.488982	31.285454	74.041202
Wetland/swamp	212.698	115.58859	77.486211
Water	0.902439	0. 564846	0.567436
Total area	**718.13789**	**718.394962**	**718.98244**

The study area was divided into three sections (upper catchment, middle catchment and lower catchment) to assist examination of factors contributing to environmental impacts of the catchment. Table 6 shows the Land Cover Land use of the three sections in 1995, 2014 and 2020, and the changes in cover over the period 1995 to 2020 and illustrates the tremendous changes that have taken place in the different sections of the catchment. Thus, all of the 26% (40km²) increase in Farmland cover in the Lower catchment happened between 1995 and 2014. Farmland also increased by 33% (163.6 to 207.4km²) in the Upper catchment in the period 1995 to 2020, and also increased by 157% (51.4 to 131.7km²) in the Middle catchment in the same period. Forest reduced from 57 1o 31km² (46%) in the Upper catchment between 1995 and 2020, most of the reduction happening between 2014 and 2020, and declined practically by 100% (22.8 to 0.8km²) in the Middle catchment between 2014 and 2020. Settlement more than doubled in the Middle section between 1995 and 2020 (9.3 to 19.03km²) and quadrupled (8.5 to 44.1 km²) in the Upper section of the catchment in the same period; The Middle catchment hosts the rapidly expanding Eldoret municipality and its suburbs, which contribute to the rapid rise in settlement. Also, the large planted commercial EATEC forest which covered much of the Middle catchment has been cleared. Wetland areas (seasonal and perennial) have also declined drastically from 55.5 to 8.9km² (89%) in the Middle section between 1995 and 2020.

Table 6: LC/LU class cover in the 3 sections of the catchment

Areas in km²									
	1995			**2014**			**2020**		
Land cover	**Lower**	**Mid**	**Upper**	**Lower**	**Mid**	**Upper**	**Lower**	**Mid**	**Upper**
Farmland	153.67242	51.54218	163.66066	193.40886	103.415193	194.391884	193.041404	131.774289	207.416799
Forest	14.399596	43.743417	57.030193	4.878066	22.767225	50.981865	3.004438	0.756116	31.144979
Settlement	2.663141	9.3224x26	8.503415	4.341246	12.858011	14.029827	21.616125	19.03x1664	33.410585
Wetland/swamp	55.509104	57.457484	99.731413	24.579747	22.61943	69.134941	9.890651	10.354517	57.247536
Water	0.246639	0.042253	0.613547	0.000647	0.339621	0.224578	0.200222	0.101267	0.267553
Total area	**226.4909**	**162.107776**	**329.53923**	**227.20857**	**161.99948**	**328.763095**	**227.75284**	**162.01784**	**329.48744**

Conclusion

The study has shown substantial changes in Land Cover/Land Use of the catchment over the 25 years studied and that, since these processes are likely to continue and even accelerate in future, action to reduce these changes are urgently needed. Land cover and land use have significant effect on the efficacy of the hydrology of any catchment and the frequently observed dry wells and dry river channels during extended dry seasons in this catchment are at least partially due to these changes. This needs to be clearly incorporated in policies encompassing development in this catchment and especially the expansion of Eldoret Municipality. Soil/land conservation in the catchment, especially in the upper catchment, and wetland rehabilitation/ conservation throughout the catchment should be prioritized.

Recommendations

It is clear that doing nothing will lead to unsustainable water supply conditions in the catchment in a few decades. We therefore recommend that immediate steps be taken to increase forest/vegetation cover in the catchment, especially in the upper zone. Active land/water conservation effort on the catchment is urgent.

Funding

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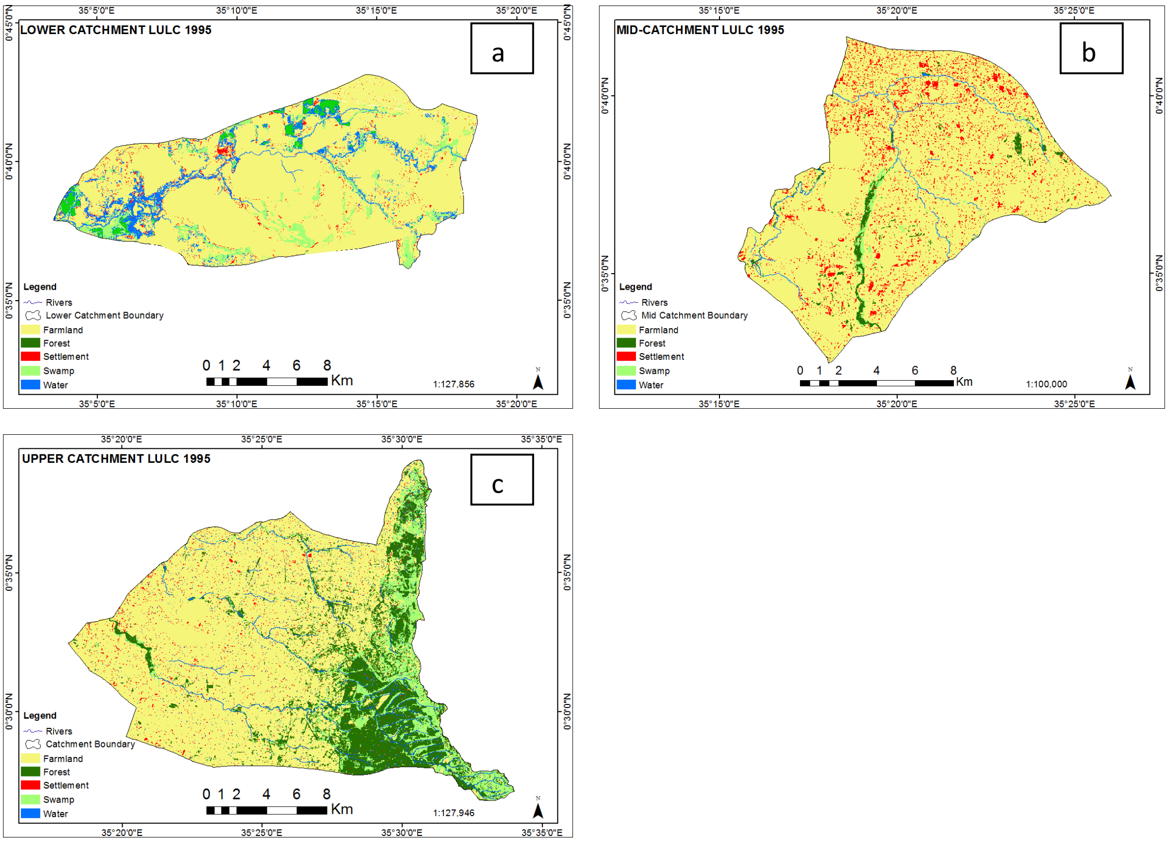
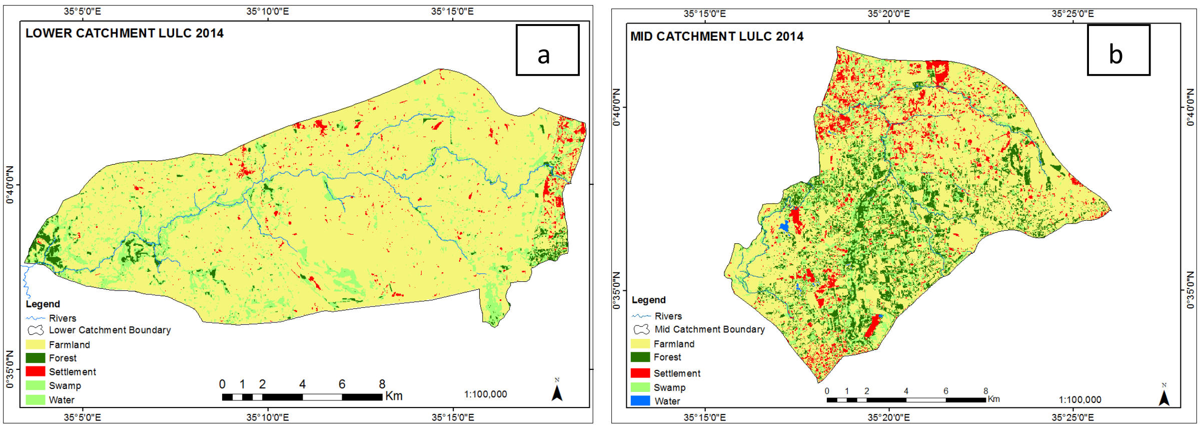
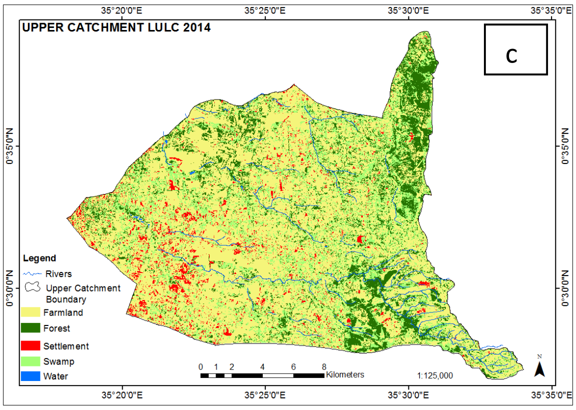
Annex 1

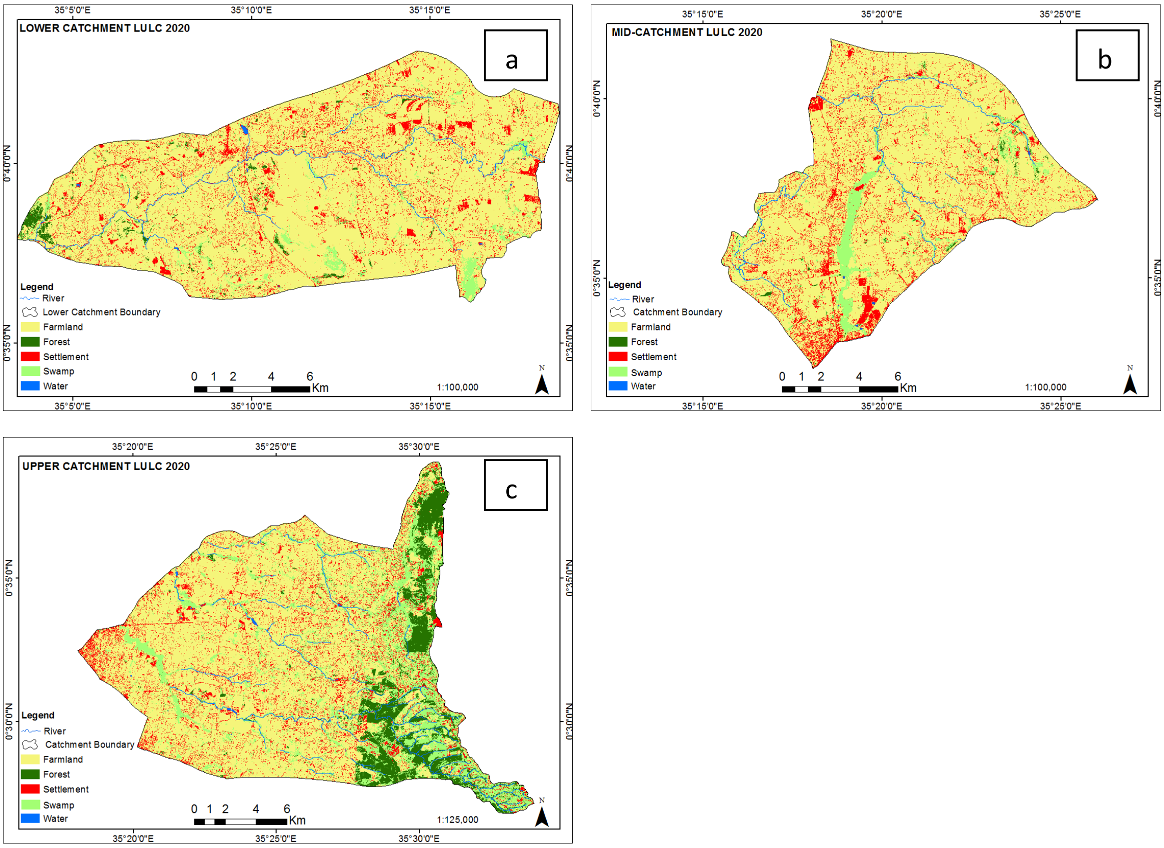


Annex 2: River Chepkoilel-Sergoit a) lower, b) mid and c) upper catchment 1995 LULC





Annex 3: River Chepkoilel-Sergoit a) lower, b) mid and c) upper catchment 2014 LULC



Annex 4: River Chepkoilel-Sergoit a) lower, b) mid and c) upper catchment 2020 LULC