ANALYSIS OF LAKE NAKURU SURFACE WATER AREA VARIATIONS USING GEOSPATIAL TECHNOLOGIES

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Abstract
The research intended to analyse the trend of Lake Nakuru water surface variation between 1984 and 2013 with the aim of identifying probable causes. Landsat images including Tropical Rainfall measuring mission (TRMM) were used to determine the lake surface level variations within the period. Supervised classification was used in generating Land Use/Land Cover changes between 1984 and 2013. The results show that changes in the lake level variations may not entirely be attributed the amount of rainfall during the period under consideration. There is consistent trend in reduction of forest cover and increase of farm or agricultural land. Forest cover increased from 30.99% to 33.73% between 1984 and 2013 while agricultural land increased from 59.12% to 68.61% during the same period. The lake water surface area had a steady increase of between 30.46 km^2 in November 2009 to 57.55 km^2 in January 2014 an increase of 27.09 km^2 which is 88.94%. In 2006 the water surface area was 35.38 km^2, it also witnessed the highest amount of rainfall but the lake water surface area did not reflect that. The rainfall data from TRMM 2009 - 2010 the difference was 36.3%, 2010- 2011 reduced to 29.8%, 2011 – 2012 increased to 32.4% and 2012 – 2013 finally increased to 36.6%. The rain gauge rainfall amounts 2009 - 2010 had a difference of 24.4%, 2010- 2011 reduced to 19.3%, 2011 – 2012 reduced further to 13.1% then 2012 – 2013 increased to 49%. The lake surface area 2009 - 2010 difference of 44.6%, 2010- 2011 increased to 46.7%, 2011 – 2012 increased further to 70.1% and 2012 – 2013 finally increased to 86.6%. This showed when rainfall amounts were falling the lake surface areas were still increasing indicating no direct correlation between the rain and the lake surface area.

Key words: Geospatial information Systems, tropical rain measuring mission, land use, land cover, supervised classification, landsat images, lake water surface area.

1.0 Introduction

Lake Nakuru is one of several shallow, alkaline-saline lakes lying in closed hydrologic basin in the eastern African Rift valley that stretches from northern Tanzania through Kenya to Ethiopia (Livingstone and Melack 1984).Typical of shallow, saline lakes around the world, climatic variations have caused large changes in its depth and salinity on annual, decadal and longer time scales, with major consequences for the lake's ecology. Daily fluctuations in heating and cooling have resulted in strong cycles of stratification and mixing (Melack and Kilham 1974). The consequences of this process include heightened potential for downstream riparian flooding during the rainy season, and a reduction of base stream flow during the dry season, both of which are serious concerns when understood from environmental and economic production perspectives. Consequently, high volume surface run-off events can increase during the rainy season while infiltration and deep percolation is reduced. Despite an increase in annual runoff, the lack of ground water recharge can result in significantly reduced dry season flows (Gene1970).

Uncalibrated preliminary hydrologic modeling of these changes suggests that annual stream discharge could increase substantially with the current scale of deforestation and agricultural conversion underway in the Njoro watershed (Baldyga et al. 2004). Without forest cover, precipitation is less likely to recharge soil subsurface storage and is more likely to result in increased runoff during and immediately after storm periods if no land management measures are taken (McDonald et al. 2002). The hydrological conditions in Lake Nakuru indicate that water levels are dependent on catchment supply through rivers such as Makalia, Nderit, and Njoro from the Mau catchment. There are also some springs within the park and waste water from Nakuru Municipality, (M. Gichuhi, 2013)

The Mau Forest Complex is thus the largest water tower in the region, being the main catchment area for 12 rivers draining into Lake Baringo, Lake Nakuru, Lake Turkana, Lake Natron and the Trans-boundary Lake Victoria. It is the source of rivers Makalia, Enderit, Njoro, Larmudiac and Ngosur that discharge into Lake Nakuru (KWS, 2002). The Mau forest complex is Kenya's largest canopy forest ecosystem and the single most important water catchment in the Rift valley and western Kenya. This water tower covers over 400,000 Ha and is the largest of the 'five water towers' of Kenya, (UNEP, 2009). Continued destruction of the forests is leading to a water crisis has resulted into that perennial rivers becoming seasonal, storm flow and downstream flooding increasing and in some places, the aquifer dropping by 100 metres while wells and springs are drying up (Lambrechts, C. (2005)). The impacts are negatively felt on major natural assets and development investments including Lake Nakuru National Park, Maasai Mara National Reserve, Sondu-Miriu Hydropower Scheme Geothermal plants near Naivasha, small hydropower plants in the Kericho tea estates and the tea growing areas in Kericho Highlands (Meyer, W. B. (1994)). The areas already facing water scarcity may get drier raising disputes and conflicts on limited water resources. The parts of the sub-region ecosystems rich biodiversity will face further encroachment and severe degradation causing more human and wildlife conflicts, (Kadi M. (2011)).

Documentation of the rising water levels in the four Ramsar sites was made using Geographic Information System (GIS) digital techniques and information extraction and representation from Landsat satellite image data for January 2010, May 2013 and September 2013 and October 2013(S. M. Onywere, 2013). Lake Nakuru showed an increase in its flooded area from a low area of 31.8 Km^2 in January 2010 to a high of 54.7 Km^2 in Sept 2013, an increase of 22.9 Km^2 (71.9%) affecting 60% of the transport infrastructure in the park, the tourism and the park main gate which is currently closed(S. M. Onywere, 2013). Lake Nakuru has shown increasing water levels since the short rains of September 2010 and was the first of the rift valley lakes to burst its bank.
The research intended to look at the trend of lake Nakuru water surface variation within the years between 1984 and 2013 with the aim of identifying probable causes and also compare it with the amount of rainfall received at that year or months when the changes took place and see if there is any correlation between rainfall amounts and the changes in the water levels.
This was to be achieved by determining the land use/land cover changes in the lake Nakuru catchment area between the same periods.
The rainfall amounts were established between 1998 and 2013 from Tropical Rainfall Measuring Mission (TRMM) and from Rain gauge on the Lake catchment area between 1984 and 2013, and comparison was made.
The lake water surface area variations were determined between 1984 and 2013 from remotely sensed images

1.1 Study Area
The study area is Nakuru lying between $0^0\ 16'$ and $0^0\ 43'$ South, and $35^0\ 41'$and $36^012'$ East. It covers an area of 2,936km^2 or 293,631Ha.The area covers 10 Divisions in Rift Valley, 9 out of the ten being in Nakuru County and one in Narok County

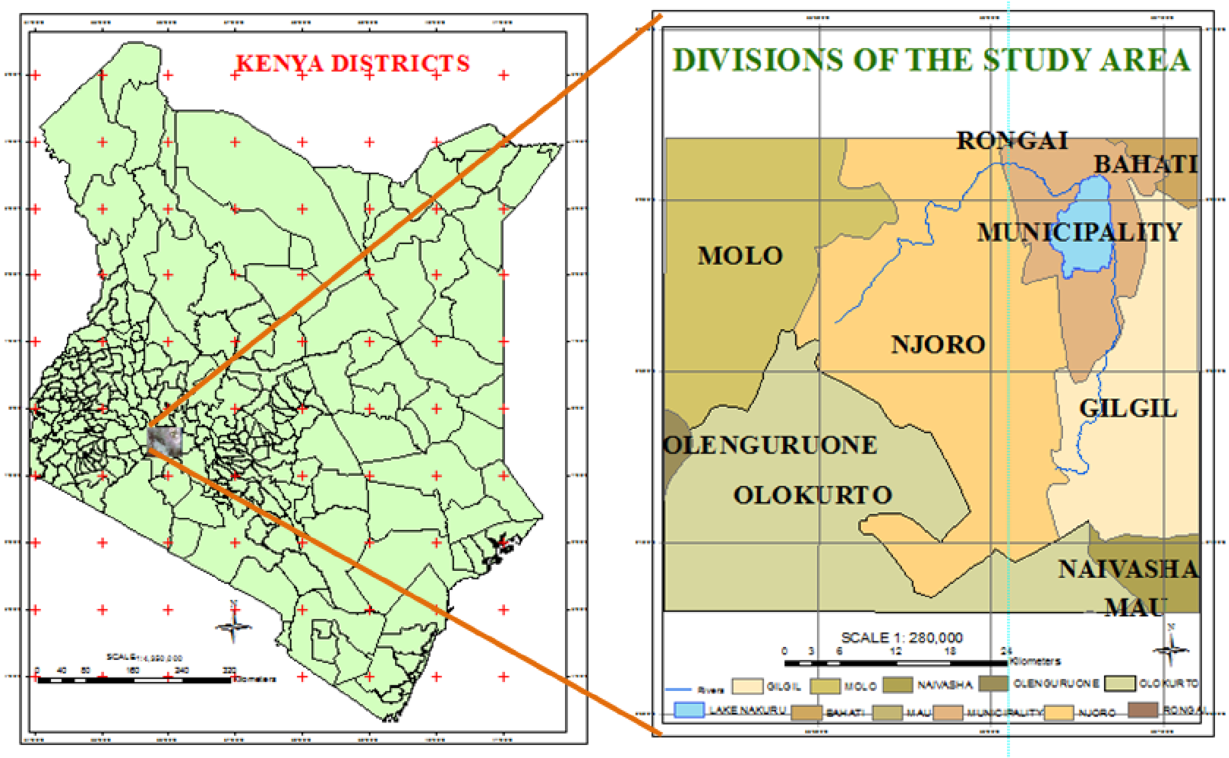


Figure 1: The maps of the study area and the administrative divisions

2.0 Methods and Materials

Data was acquired from United States Geological Survey (USGS) website. . In this research Landsat 5, 7 and 8 were used. Landsat 7 images, the resolution of the image are 30metres and 15 metres for band 8. Landsat 7 developed a problem from 31st May 2003 when a component of the ETM+ optical scanning system (called the scan line corrector or "SLC") failed, leaving wedge-shaped spaces of missing data on either side of the images it has strips due to SLC malfunctioning. The data is downloaded in a zipped file. The data is unzipped to the working folder. The data with the stripes are de-stripped use a mask file, destripping is process of closing the gaps that had been created by the sensor failure. The data is then imported to ERDAS Imagine from TIFF to ERDAS file format. The bands are then layer stacked to produce a composite. Sub setting is performed to generate the area of study. Principal Component Analysis is performed, for the purpose of training the data. Supervised classification was carried out where six classes were distinguished namely Forest, Built-Up area, Grassland, Farm, water and bare land. After classification accuracy assessment was then carried out

The rain gauge rainfall data was from a weather station in Nakuru: 637140 (HKNK) Latitude: -0.26 | Longitude: 36.1 | Altitude: 1901.The data found in this station are from 1957, the data collected from this research were from 1984 to 2013. The data were captured daily, the data collected from the website was then copied to an excel sheet where the totals were computed. Then the data were combined in excel analysis were performed where bar graphs, line graphs were generated to establish the trend.

Tropical rainfall measuring mission (TRMM) data were downloaded from the National Aeronautics and Space Administration **(**NASA**)** website

The TRMM data started being used from 1998 and that is why the data is from 1998, the rainfall data was taken for 11 years which was from 1998 and 2013. The data is totaled for every year and then this figure is compared with the lake surface area and also the data from the rain gauge. The data was picked that correspond to the available images, except for 1997 which did not have images since Landsat images for that year were not available.

The TRMM data is always in a grid of 0.25^0 by 0.25^0 which is 25 km by 25 km. The study area covered 50 by 57 km which was covered by six grids. The study area was used to clip the TRMM data.

2.1 Lake Surface Water Variation Data

For the purpose of analyzing lake Surface water variations the following Landsat images were used: - 1984, 1986,1995, 2000, 2001, 2002, 2003, 2005, 2006, 2007, 2008, 2009 June and November, 2010 January and December, 2011 January and September, 2012, 2013 May and October, 2014 January, February and July. These were a total of 24 images. Some of these images could not have been used in the Land use land cover changes due to cloud cover and some were affected by SLC stripped which started in May 2003. The lake outline was digitized from the images so as to get the various sizes at different times. Various maps were generated for lake water surface area in square kilometres.

2.2 Land Use Land Cover

The images that were used for the land use land cover changes were 1984, 1995, 2003 and 2013. The images were classified in six classes namely: - Forest, Built-Up area, Farms, Grassland, Water and Bare land. Supervised classification was used to generate the land covers. The softwares used were ERDAS Imagine, ArcGIS and Microsoft excels for the processing of the data. The area of the land use Land cover was generated by ERDAS Imagine in Hectares. For the land use/Land cover after the images were subset, they were classified through supervised

3.0 Results

Table 2: Derived data from NASA website for Tropical Rainfall Measuring Mission (TRMM) 1998 – 2013
Graph 1: TRMM total Rainfall Amounts from 1998 to 2013 generated from table 1 above

Year	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Totals
YR2013	270	116	717	1498	565	651	750	943	802	356	526	685	7879
YR2012	96	123	301	1051	1191	664	516	571	680	871	653	924	7641
YR2011	226	176	617	518	665	715	479	920	783	827	1267	299	7492
YR2010	467	1061	1060	1055	700	516	436	432	693	678	412	356	7866
YR2009	331	161	136	813	849	240	230	341	479	633	467	1090	5770
YR2008	178	195	759	723	471	471	629	625	628	998	725	104	6506
YR2007	453	699	403	744	888	657	726	933	882	480	417	656	7938
YR2006	275	249	827	1171	743	411	365	726	625	512	1494	1205	8603
YR2005	201	239	450	454	1064	535	538	699	541	325	235	133	5414
YR2004	399	328	389	1221	342	332	459	769	374	381	418	546	5958
YR2003	290	88	472	1203	1519	578	459	1209	424	468	413	168	7291
YR2002	478	314	695	1345	748	427	503	470	176	499	697	936	7288
YR2001	432	474	560	919	493	760	667	887	791	804	630	210	7627
YR2000	250	111	271	474	570	464	597	759	467	432	800	474	5669
YR1999	366	113	938	677	663	371	579	702	362	424	767	575	6537
YR1998	1246	723	312	891	1331	779	551	479	548	565	460	103	7988

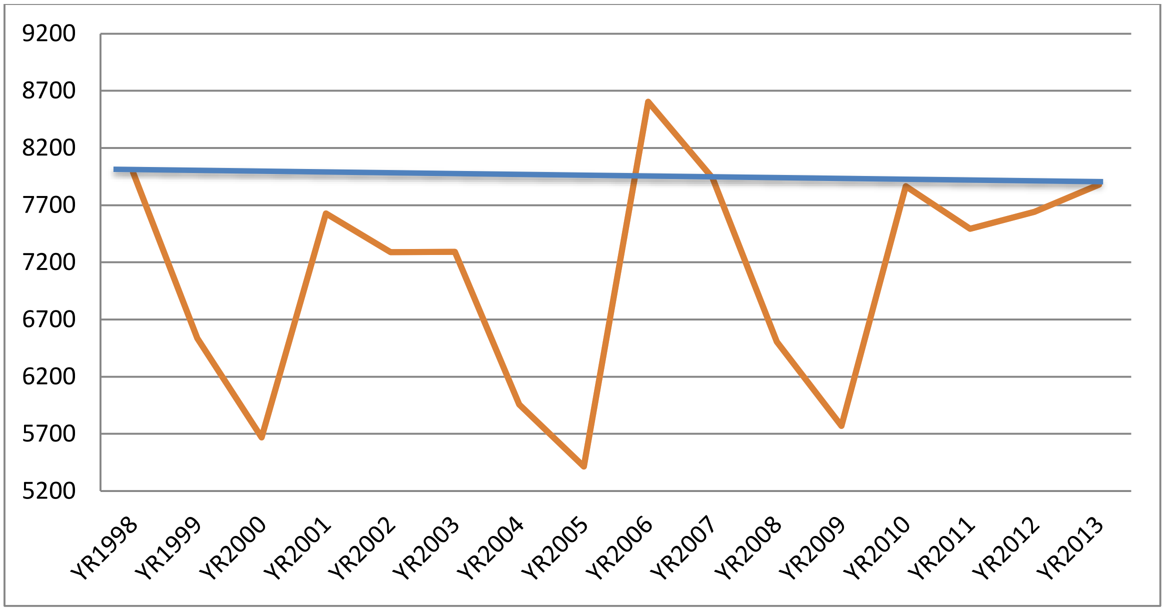


Table 2: Rainfall data from the rain gauge 1997 to 2013

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
YR2013	19	1	178	248	102	140	162	111	112	35	51	62	1219
YR2012	0	26	92	138	85	36	77	78	98	177	55	62	925
YR2011	1	0	84	58	74	82	281	130	143	58	41	22	976
YR2010	19	3	4	66	111	36	91	119	70	53	40	7	619
YR2009	15	137	30	78	162	9	16	27	44	56	68	176	819
YR2008	13	6	58	52	43	39	73	42	94	167	83	16	686
YR2007	32	145	23	127	108	107	154	133	143	96	36	200	1304
YR2006	21	10	95	130	146	41	45	87	66	48	171	105	966
YR2005	19	3	83	77	167	95	51	107	112	63	14	20	813
YR2004	49	15	36	221	114	45	25	105	50	62	45	81	847
YR2003	60	2	73	72	302	84	88	176	65	85	55	54	1115
YR2002	38	19	123	204	127	50	87	71	11	130	86	195	1142
YR2001	63	24	75	233	62	133	140	188	96	92	106	16	1229
YR2000	4	1	84	41	39	41	103	153	44	53	106	34	704
YR1999	0	0	0	11	0	0	0	0	4	40	65	76	197
YR1998	84	62	70	84	183	92	61	76	82	47	70	4	916
YR1997	10	22	20	261	90	63	113	77	35	179	228	145	1244

Graph 2: Derived rain gauge from a rain gauge situated near Menengai crater

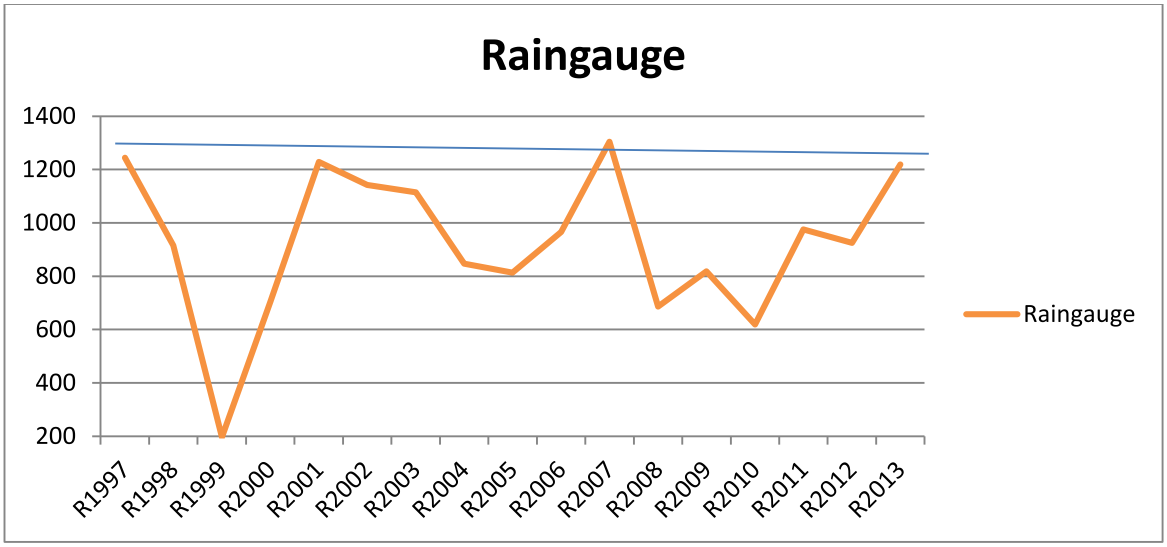


Table 3: Lake Surface Areas in km² generated from digitization of the lake surface area from Landsat images

	Year	Month	Lake Water Surface Area in km²
1	1984	November	40.09
2	1986	January	37.23
3	1995	January	31.28
4	2000	January	40.39
5	2001	April	34.59
6	2002	February	35.52
7	2003	February	35.37
8	2005	June	38.13
9	2006	January	35.38
10	2007	December	40.28
11	2008	June	38.05
12	2009	June	36.18
13	2009	November	30.46
14	2010	January	32.00
15	2010	December	44.04
16	2011	January	43.12
17	2011	September	44.69
18	2012	December	51.82
19	2013	May	53.55
20	2013	October	56.83
21	2014	January	57.55
22	2014	February	56.28
23	2014	July	55.61

Graph3: Trend of the Lake surface area in square kilometre between 1984 and 2014

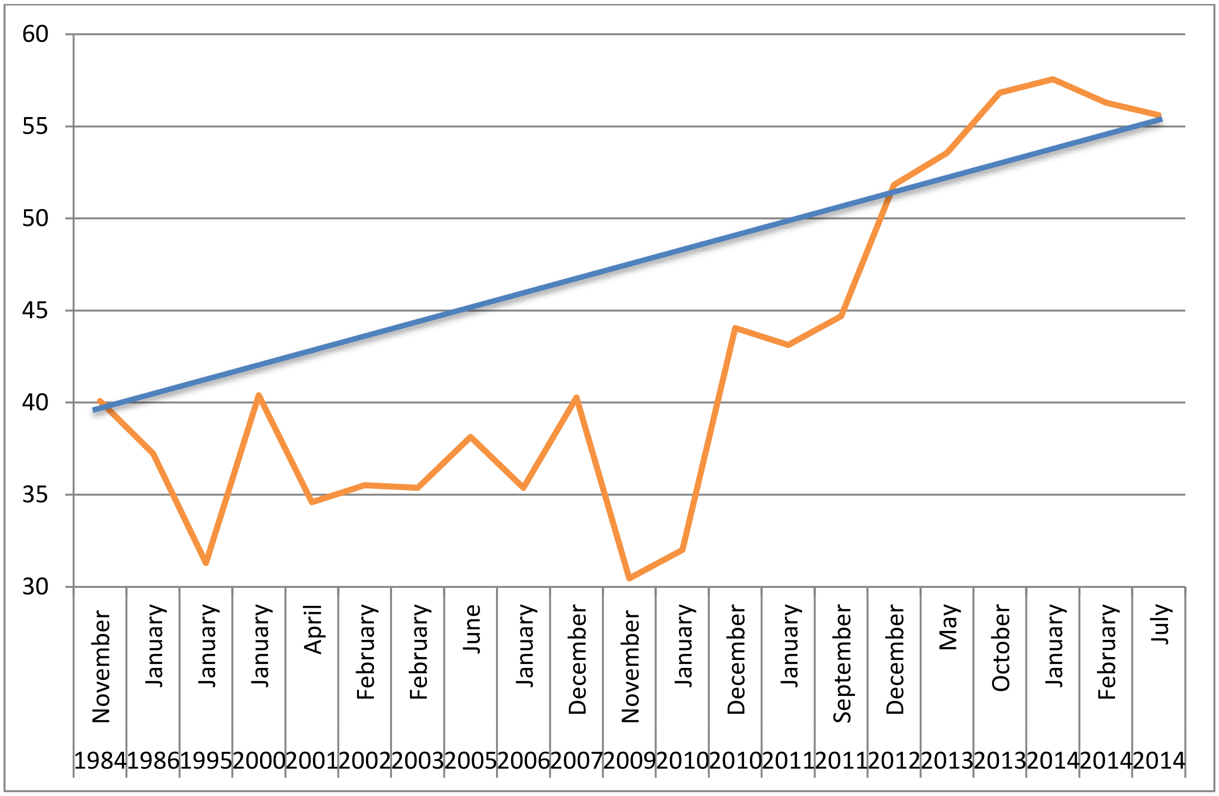
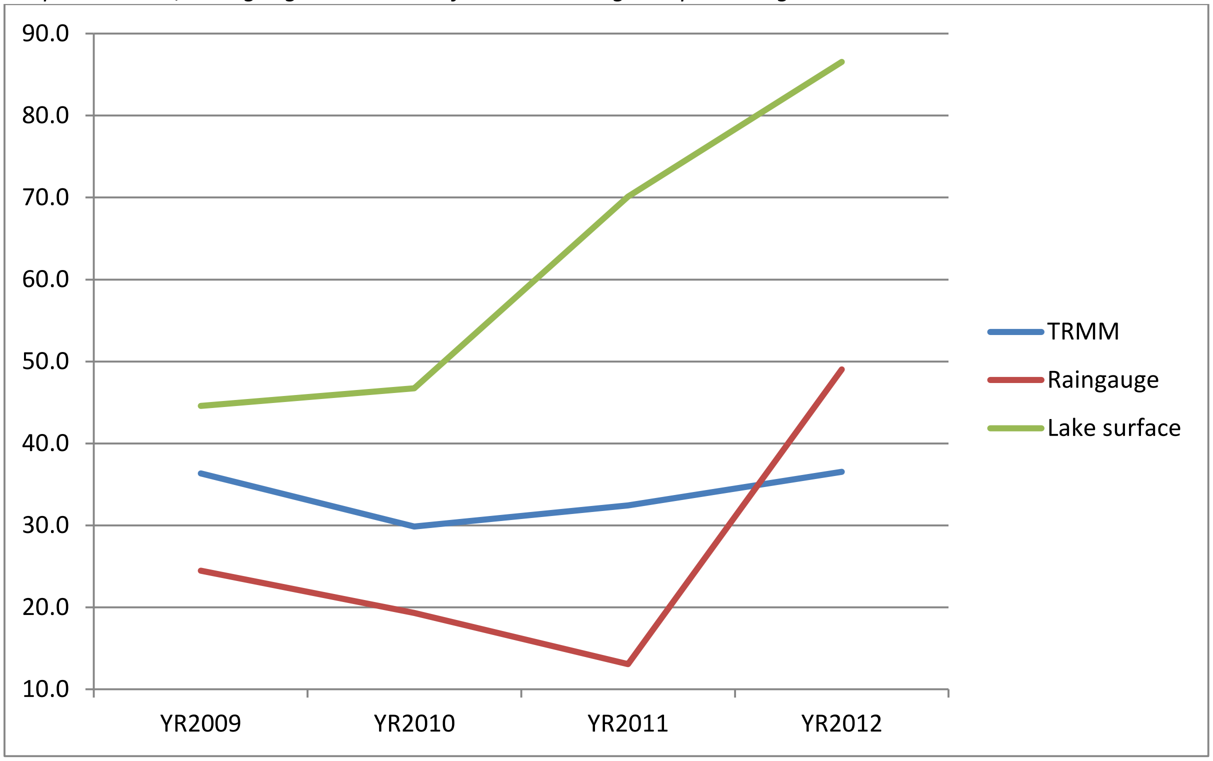
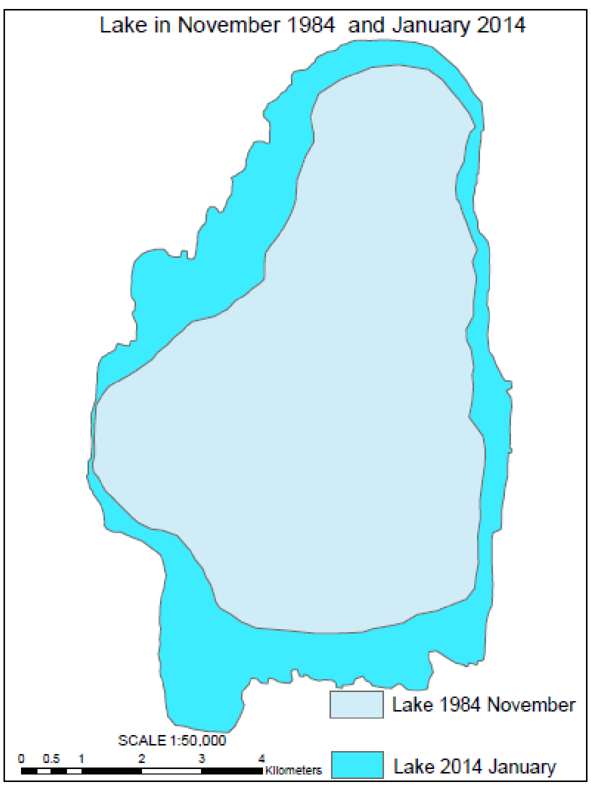


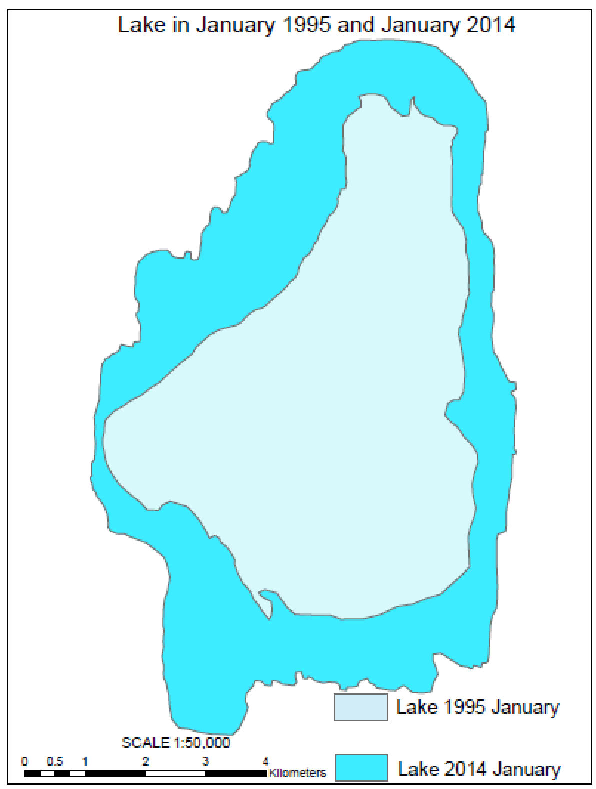
Table: 4 The differences in TRMM, Rain gauge and lake surface area in Percentages between 2009 - 2013

Year	TRMM	Rain gauge	Lake surface area
2009 - 2010	36.3	24.4	44.6
2010 - 2011	29.8	19.3	46.7
2011 - 2012	32.4	13.1	70.1
2012 - 2013	36.6	49.0	86.6

Graph 4: TRMM, Rain gauge and Lake surface area changes in percentages between 2009 and 2013







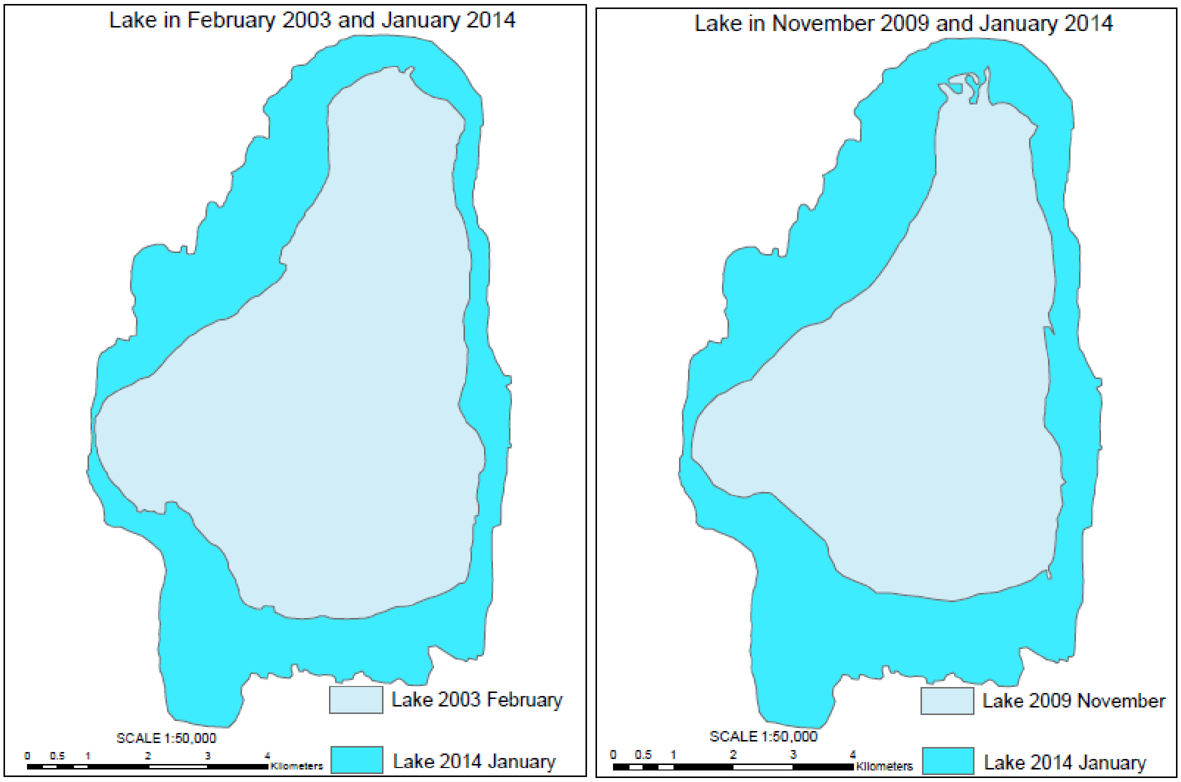


Figure 2: Lake Water surface area in November 1984, January 1995, February 2003 and November 2009 overlaid on January 2014 lake area which was used as the reference

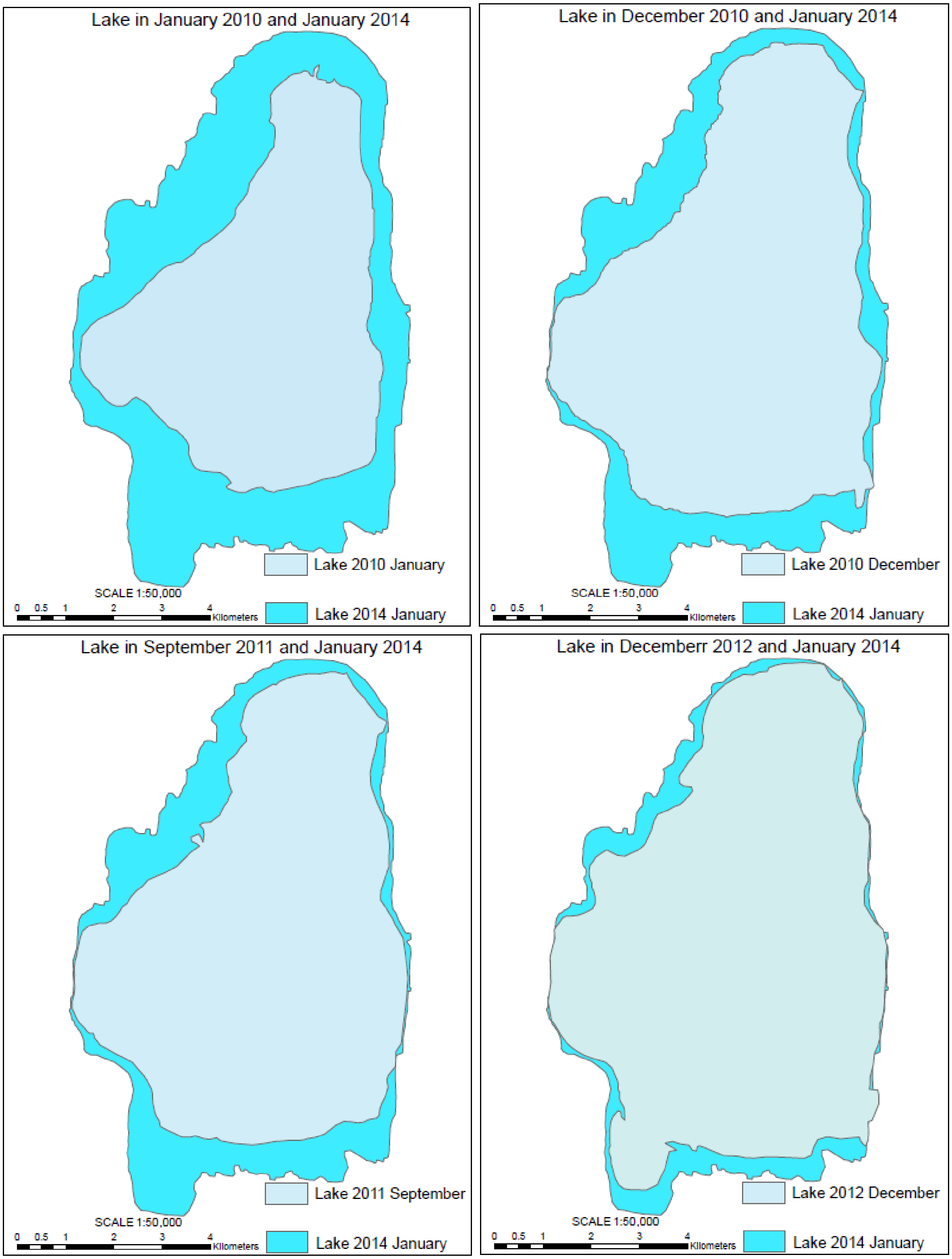


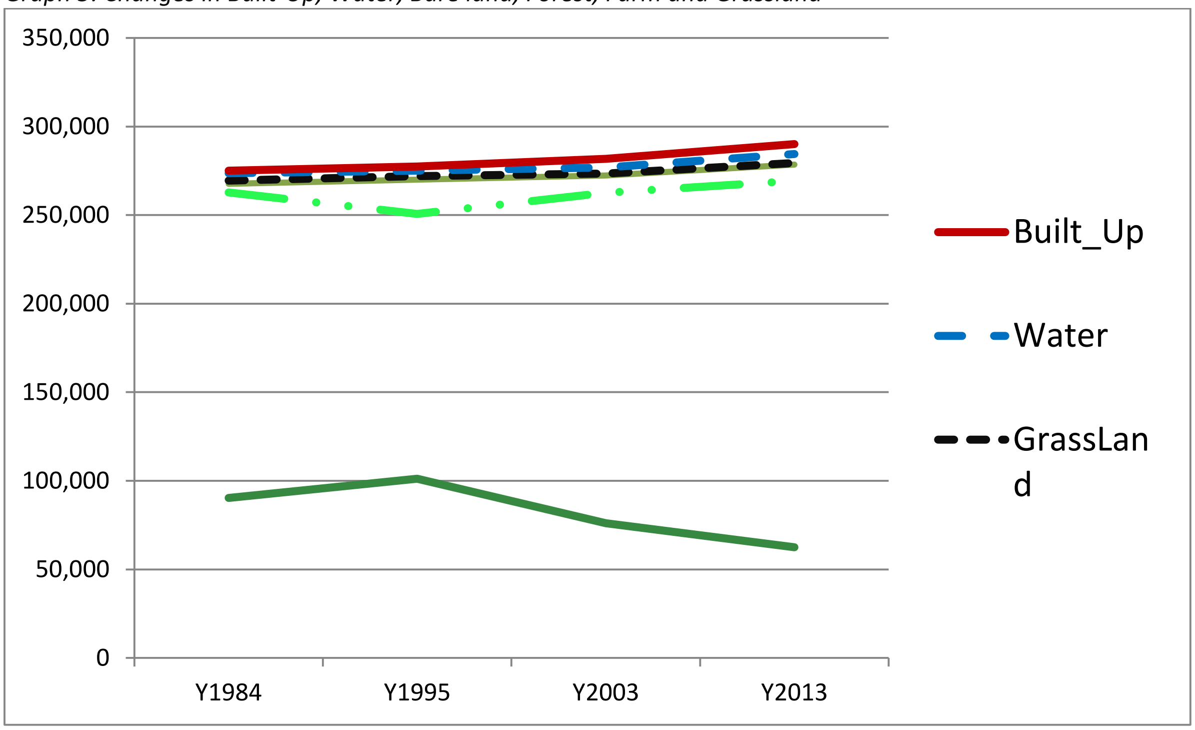
Figure 3: Lake Water surface area in January 2010, December 2010, September 2011 and December 2012 overlaid on January 2014 lake area which was used as the reference

Table 5: land use land cover changes

LAND USE LAND COVER CHANGES IN HECTARES

Year	1984	1995	2003	2013
Forest	90,376	98,371	76,045	62,427
Built-up	1,473	2,416	4,759	5,615
Grass Land	18,350	18,823	11,027	9,259
Farm	172,413	149,542	186,568	200,095
Water	4,122	3,092	3,443	4,998
Bare land	4,919	19,409	9,810	9,259

Graph 5: Changes in Built-Up, Water, Bare land, Forest, Farm and Grassland



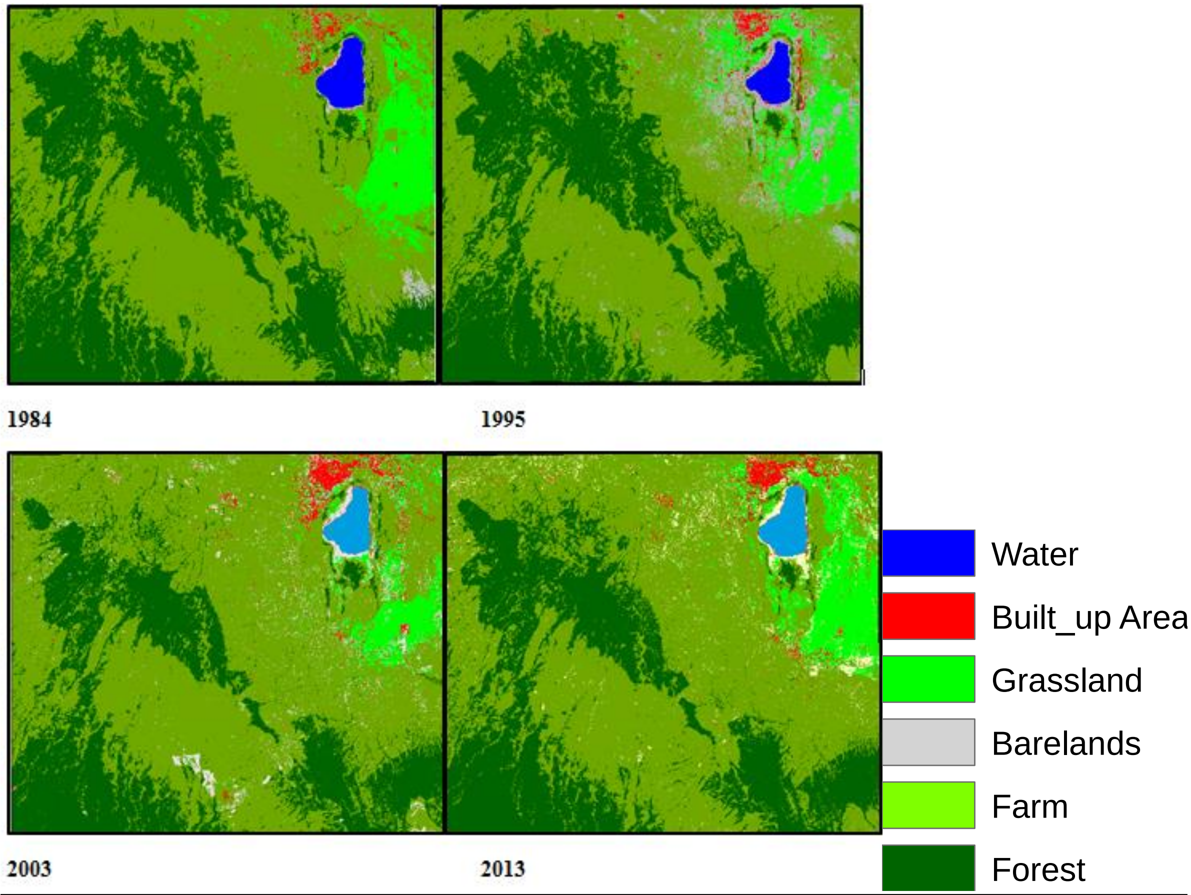


Figure 4: Land use land cover changes 1984, 1995, 2003 and 2013

Table 6: land use land cover changes in percentages

Class	Area in Ha(1984)	% Area	Area in Ha(1995)	% Area	Area in Ha(2003)	% Area	Area in Ha(2013)	% Area
Forest	90,376	30.99	98,371	33.73	76,045	26.07	62,427	21.40
Built-up	1,473	0.51	2,416	0.83	4,759	1.63	5,615	1.93
Grassland	18,350	6.29	18,823	6.45	11,027	3.78	9,259	3.17
Farm	172,413	59.12	149,542	51.27	186,568	63.97	200,095	68.61
Water	4,122	1.41	3,092	1.06	3,443	1.18	4,998	1.71
Bare land	4,919	1.69	19,409	6.65	9,810	3.36	9,259	3.17
Total Area	291,653	100.00	291,653	100.00	291,652	100.00	291,653	100.00

4.0 Discussions

Graph 3 shows that from 1984 to December 2010 the lake water surface area has been fluctuating between 30 to 40 km^2 which is a span of 26 years. November 2009 the lake water surface area was 30.46 km^2 and January 2014 the surface area was 57.55 km^{2}an increase of 27.09 km^2 which is 88.94% in a span of 5 years.

The graph also indicates that in January 1995 and November 2009 this when the lake surface area was low, 2009 indicating was the lowest.

Figure 2 and Figure 3 show how the lakes surface area has been varying from 1984 to December 2012 with the surface area of 2014 used as a reference. The actual figures of the changes are presented on table 3.

According to the data on Table 1 TRMM data the years 2005, 2006 and 2007 received the highest amount of rainfall which were 5414 mm, 8603 mm and 7938mm the changes being 3189mm and 665mm. Table 2 the rainfall amounts from rain gauge of the same years 2005, 2006 and 2007 were 813mm, 966mm and 1303 with differences of 153mm and 337mm. Table 3 for the same years 2005, 2006 and 2007 indicate the surface areas were 38.13 km^2, 35.38 km^2 and 40.28 km^2 differences of 2.75 km^2 and 4.9 km^2 . The above indicates that there is no direct correlation between the amount of rainfall received and the changes in the observed lake water surface area.

Graph 4: Indicates that from TRMM between 2009 and 2010 the difference was 36.3% then reduced to 29.8%, increased to 32.4% and finally to 36.6%. The rain gauge starts with a difference of 24.4%, reduces to 19.3%, reduces further to 13.1% then increases to 49%. The lake surface area starts with a difference of 44.6%, increases to 46.7%, increases further to 70.1% and finally to 86.6%. This shows when rainfall amounts were falling the lake surface area was still increasing indicating no direct correlation between the rain and the lake surface area.

Graph 4: Indicate changes of TRMM, rain gauge and lake surface areas. The data taken were from 2009 to 2013 where the differences were given in percentages. It shows when the rainfall amounts were falling the lake surface areas were increasing at a higher rate; this enhances the point that there is no direct correlation between the rainfall and the lake surface area changes.

From table 6 the following was observed: The forest 1984 was 30.99%, increased to 33.73% in 1995; the reason for increase is that shamba system was practiced since 1910 and was banned in 1987 and reintroduced in 1994. The system was abused because instead of replant trees where they had been harvested, they did not instead they encroached deeper in the forest and destroyed more trees. Then there was a decrease in 2003 to 26.07% and further reduced to 21.40% in 2013.

Built-Up area 1984 stood at 0.51%, increased to 0.83% in 1995, increased to 1.63% in 2003 and finally to 1.93% in 2013.

Grassland stood at 6.29% in 1984, increased to 6.45% in 1995, reduced to 3.78% in2003 and finally reduced to 3.17% in 2013

Farm stood at 59.12% in 1984, reduced to 51.27 in 1995, this could be explained by the ban on shamba system in 1987. Then it increased to 63.97% in 2003 and finally increased to 68.61% in 2013.

Water stood at 1.41% in 1984, reduced to 1.06% in 1995, increased to 1.18% in 2003 and finally increased to 3.17% in 2013.

Bare land stood at 1.69% in 1984, increased to 6.65% in 1995, reduced to 3.36% in 2003 and finally reduced to 3.17% in 2013.

5.0 Conclusion

The research intended to look at the trend of lake Nakuru water surface variation within the years between 1984 and 2013 with the aim of identifying probable causes and also compare it with the amount of rainfall received at that year or months when the changes took place and see if there was any correlation between rainfall amounts and the changes in the lake water surface area.

Maps generated show how the lake water levels have been changing within the period

Maps generated of the lake catchment area shows the land use land cover changes between 1984, 1995, 2003 and 2013

In June 2009 and November 2009, there was a reduction of 5.72 km^2 in the lake surface area in a span of 4 months. The amount of rainfall from TRMM was 5770mm.

December 2010 and September 2011, the difference in lake surface water area was 44.04 km^2 and 44.69 km^2 respectively; representing a difference of 0.65 km^2 but the change in rainfall is from 7866mm in December 2010 and 7492mm in September 2011, a difference of 374mm.

December 2012 and October 2013 water levels were 51.82 km^2 and 56.83 km^2 a difference of 5.01 km^2, the rainfall amounts were also 7641mm and 7879mm respectively a difference of 238mm.

Between November 2009 and January 2010 the lake water surface area had raised from 30.46 km^2 to 32.00 km^2 an increase of 1.54 km^2 in one month.

Although 2006 received the highest amount of rainfall of 8603mm and 2007 received rainfall of 7938mm a of difference of 665mm but did not reflect on the lake water surface area change which increased slightly from 35.28 km^2 to 40.28 km^2 an increase of 4.9km^2

The research established that there was no correlation between the amount of rainfall received and the change of the lake water surface area.

Years like June 2009 and November 2009 showed a drastic fall in the lake water surface level and the amount of rainfall had not fallen with the same margin.

6.0 Recommendations

In June 2009 and November 2009, there was a reduction of 5.72 km^2 in a span of 4 months. The amount of rainfall from TRMM was 5770mm. Therefore, the cause of sudden drop in water surface level needs to be investigated.

Between December 2010 and September 2011, the difference in water surface area was 44.04 km^2 and 44.69 km^2 respectively; representing a difference of 0.65 km^2 but the change in rainfall is from 7866mm in December 2010 and 7492mm in September 2011, a difference of 374mm. These differences of rainfall not being reflected on the change in the lake water surface area need to be investigated to ascertain the possible reason.

Investigate the other reasons for sudden reduction in the lake surface water area between June 2009 and November 2009, which was 5.72 km^2 in a span of 5 months and the sudden rise in lake surface area between November 2009 and January 2010 rose from 30.46 km^2 to 32.00 km^2 an increase of 1.54 $km^{2\ in}$ in one month.

Acknowledgement

I am grateful to the Chairman of the Department of GEGIS Dr. Thomas .G. Ngige who according me all the support I required from the department. Thanks to my co-author Professor E.H. Waithaka whom by working together we were able to come up with those exciting results.. All members of Staff of JKUAT- GEGIS department who I constantly consulted and they were able to assist where they could. I would like to thank Tom Kiptenai from RCMRD for the support he gave when I needed help from him.

May the Almighty God bless you all

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