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Impact of climate change on land use dynamics along River Ona, Nigeria

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Abstract

Climate change has direct influence on environment and human existence. Climate change has been a monster posing threat to the hydrological cycle, hence the flow discharge of rivers. Therefore, it is necessary to study its effects on the flow of rivers thereby producing measures to alleviating its effects. In this study, the effects of land cover and weather conditions between 1967 and 2017 on the flow discharge of River Ona were investigated by making use of the climatic data (rainfall and temperature). The statistical variations in temperature and rainfall data were assessed using Statistical Program for Social Science (SPSS) in order to depict the linear variation, regression and correlation of the prevailing climate of the area The results showed that year 1998 and 1999 have the lowest and highest rainfall values respectively. The land-use maps show there is gradual increment in area of lands that are built-up but gradual reduction in the vegetal area. The runoff of River Ona would increase because of wetter climate caused by high rainfall in 1999. In addition, over the years, runoff severity tends to increase because of land development, giving rise to the replacement of vegetal areas by built up areas, which have low retention capacity in the area. The findings from this study can be used to predict the discharge of river given other weather and environmental factors.

Keywords: *Climate change; Land use dynamics; GIS; River Ona*

Introduction

Climate is the weather condition over a long period. The impacts of climate and hydrological changes cover all spatial scales, (Lahmer *et al.*, 2001; Coulthard *et al.*, 2005). Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer (IPCC, 2007). The Intergovernmental Panel on Climate Change, IPCC (2007) defined climate change as a significant change of climate, which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods. The climate system is connected with the water cycle. Hence, any perturbation change in climate would result in the hydrological cycle. Obviously, climate change variables developed by IPCC are the most useful data to comprehend the climatic condition whether it is at global level or national level (Mearns *et al.*, 2001). A number of factors affects the discharge of a river namely the drainage basin, soil and rock type, vegetation cover, human activity, weather and climate. Weather and climate are most influential factors that affect the flow discharge of a river. Adelalu (2012) reported that in recent years, rainfall and temperature change in output have been major breaking news in many parts of the world. The influence is seen in many sectors of life. Water resources are scarce in many regions while some loom in floods. Arnell (2014) stated that climate change is foreseen to increase water stress in some parts of the world and increase river discharge in others. This emphasizes the need to assess and take consideration to climate change impacts in the adaptive management of water resources. The effect on river discharge by changes in precipitation (P), potential/actual evapotranspiration (Ep; Ea) and temperature (T) is an important factor in environmental (transport of nutrients, sediment and habitats of flora and fauna), agricultural (drainage and flooding) and economical applications, such as: water supply, flooding, engineering, and agro economics. Therefore, it is necessary to have good estimates of future river discharges in order to discuss better the effects of climate change. Projection of future climate trend will be highly essential for environmental planning and management. Changes in climate conditions may promote the events of draught or flood extremes (IPCC, 2007; Bates *et al.,* 2008). Therefore, the investigation on the climate change impacts on the present and future hydrological variability is highly demanded. Little systematic research has focused on the distribution patterns of the impact of climate change using GIS techniques such as Arc GIS. This study investigated the impact of climate change on the flow discharge of River Ona by utilizing the rainfall pattern of River Ona over the years, generate the DEMs and land use maps of River Ona Catchment using GIS and remote sensing. Others include generation of the runoff maps of River Ona Catchment that depicts flow discharges over the stretched years and analyse the relationship between rainfall and flow discharge of River Ona.

Materials and Methods

Description of the study area

River Ona in Eleyele catchment's area is on Longitude $6^{o}43^{1}0^{11}$N and Latitude $30^{o}43^{1}60^{11}$E as shown in Figure 1. There are two streams feeding the river (one of which takes its source from the north of the International Institute of Tropical Agriculture (IITA) and flows through the Institute, while the other takes its source from the south east of IITA, and form a confluence at Ojoo area and then flows into the reservoir at Eleyele (Areola and Akintola, 1980 & Bello *et al*., 2019).

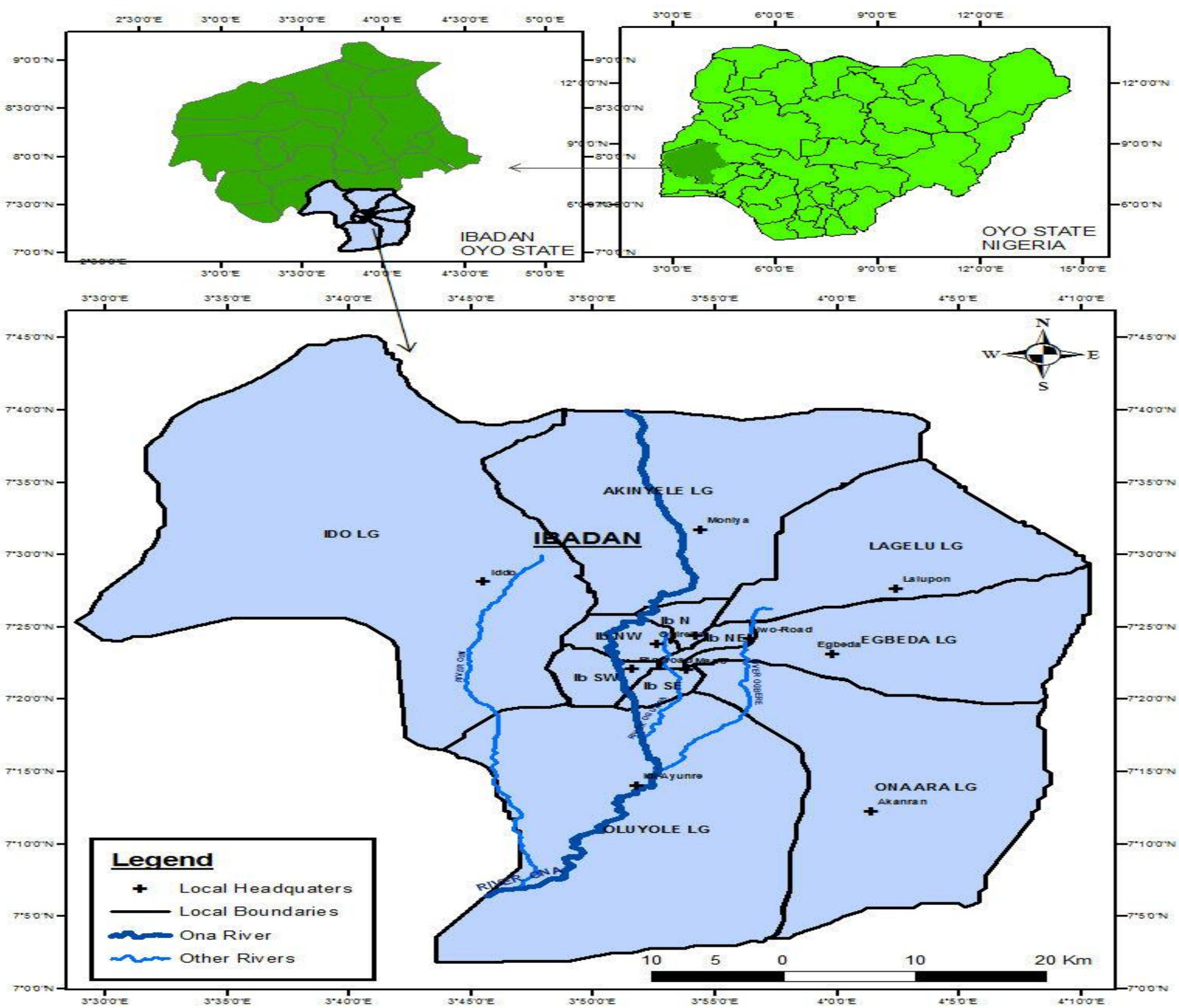

Figure 1: Map of the study area

Eleyele catchment, Ibadan has a tropical wet and dry climate. Ibadan's wet season runs from March through October while November to February forms the city's dry season. The mean total rainfall for Ibadan is 1420.06 mm, falling in an average of 109 days. The mean maximum temperature is 26.46^{o}C, minimum 21.42^{o}C and the relative humidity is 74.55 % (Adewale *et al*., 2011).

Climatic data

The climatic data (1967 to 2017) used for this study are the temperature and rainfall data representative of River Ona, Ibadan. The statistical variations in temperature and rainfall data were assessed using Statistical Program for Social Science (SPSS) in order to depict the linear variation, regression and correlation of the prevailing climate of the area.

Hydrographical maps

The hydrographical map entails the flow region of River Ona, its tributaries and tributaries flow network and pattern. The geographical maps required for generating the hydrographical maps were obtained from the Ministry of Federal Survey Nigeria and Google earth. The input maps were imported in to Arc-GIS environment and thereafter geo-referenced to its correct coordinates through geo-referencing utility within the Arc GIS environment. The extraction of the hydrographical data from the input maps involved; Rectifying, Digitizing, Laying-out and exporting. Rectifying was done to correct the input map with the exact geo-referenced values of the map, while digitizing was the extraction and carving out the necessary features needed in the input map of River Ona features with its catchment, tributaries, settlements and roads within the catchment. Laying-out was done to give necessary attributes of the map to the hybrid map. After laying out the map, the land-use map was then being exported from the ArcGIS environment in a TIF format.

Flow discharge

Flow discharge analysis of River Ona were based on the combined effects of rainfall, topography and land use pattern within River Ona catchment, the flow discharge analysis and modeling consequently involved generating the Digital Elevation Measurement (DEM) model and Land use model of River Ona catchment by interpolating with ArcGIS with considerations given to the environmental condition of the catchment. The rainfall data were attributed to a point shape-file; the point features were then interpolated using natural neighbour approach to produce a spatial variation of elevation with the catchment.

Digital Elevation Measurement (DEM)

Remote Sensing technology technique was used to retrieve the elevations of selected stations within River Ona catchment. DEM was generated from these elevation data by interpolating with ArcGIS. The elevation data were attributed to a point shape-file; the point features were then interpolated using natural neighbour approach to produce a spatial variation of elevation with the catchment.

Land-use map

Satellite imagery over River Ona catchment was retrieved and then processed by downloading the vector data, pre-processing the data, loading it into the ArcGIS, extracting the shape file for the study area and then adding ESA land cover to produce the land-use map. These satellite imageries were obtained from Google earth in many magnified bits to ensure accurate details. The input maps were imported in to ArcGIS through a process known adding of Data. The maps were geo-referenced within the ArcGIS environments. The extraction of the land use data from the input maps involved; Rectifying, Digitizing, Laying-out and exporting, digitizing implied extracting features for the input map within and the land use pattern of area such as shrubs, rivers, forested, industrial, residential and paved areas. Laying-out involved gave necessary attributes of the map produced. After laying out the map, the land-use maps were then exported from the ArcGIS environment in a TIF format.

Runoff modelling

The rainfall variations maps of Ibadan were made from the climatic data (1967 – 2017). The slope map, which showed the variation of the rate of change of elevation with distance in degree, were generated from the DEM of the catchment but making use of the slope icon at the ArcGIS Toolbox. The runoff map, which represents the flow discharge model, was obtained by analysing the combined effects of rainfall, land use variation, DEM and slope of the area. These procedures are as depicted in Figure 2.

Projected discharge of river ona

Flow discharge analysis of River Ona was done in order to predict and model future discharge based on the correlation between rainfall and flow discharge. SPSS was used to produce the linear regression value while ArcGIS was used to analyze and formulate the future flow discharge models.

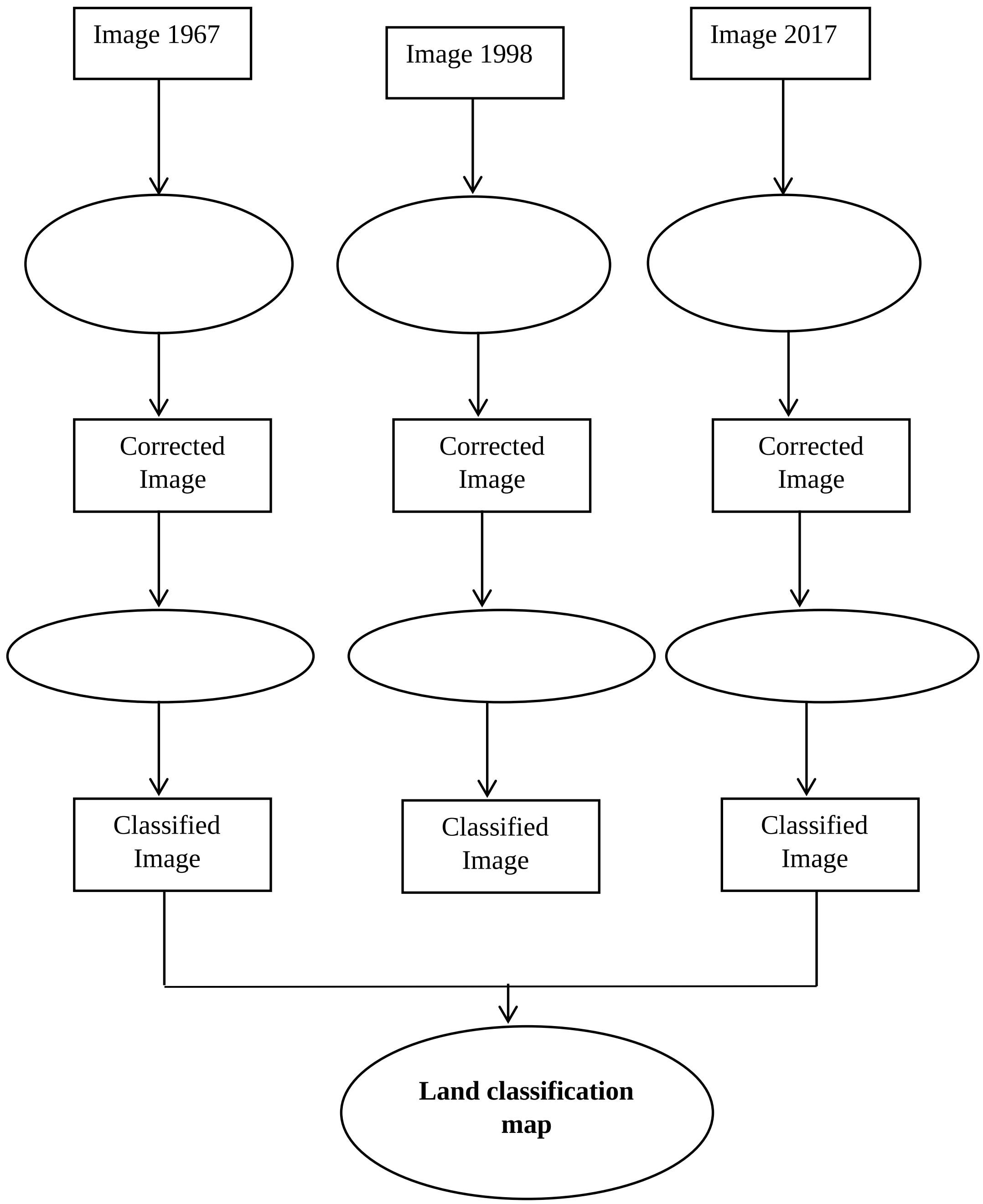

Figure 2: Flow-chart for land classification map

Results and Discussion

Rainfall data

The peak rainfall data of River Ona from the year 1967 to 2007 are summarised in Table 1. The peak rainfall ranges from 84.83-151.29 mm; while year 1998 has the least peak rainfall value year 1999 has the highest peak rainfall value. The peak rainfall graph gradient line shows a gradual declination for rainfall over the years. From the peak rainfall gradient line, peak rainfall of river Ona was obtained to be 107.55 mm.

Peak rainfall linear equation is: $R_n = -0.1334n + 114.2$ …………………… (1)

where, R_n is Rainfall in mm……. n = Year

Table 1: Maximum annual rainfall of river Ona catchment

S/N	Year	Peak Rainfall Value (mm)
1	1967	114.12
2	1977	123.18
3	1987	127.9
4	1997	91.43
5	1998	84.83
6	1999	151.24
7	2000	103.71
8	2001	107.475
9	2002	126.28
10	2003	95.25
11	2004	109.53
12	2005	100.35
13	2006	114.55
14	2007	90.72

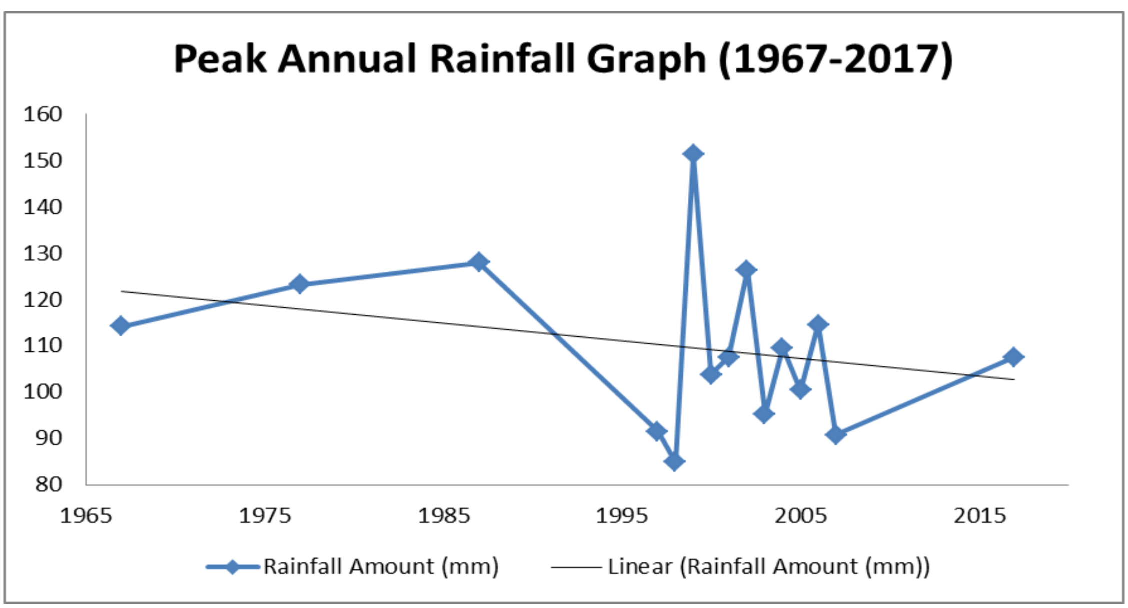

Figure 3: River Ona Peak Annual Rainfall Graph (1967 – 2017)

Digital elevation models

The Digital Elevation Models (DEMs) of River Ona over the stretched years are as shown in Figure 4. The elevation variation was found to be between 140 m – 300 m. The areas in blue are areas of high elevation while those of tinted blue are of low elevation. The elevations of settlements at the northern part of the models generally show high values with gradual reduction in elevation towards the south over the years. The DEMs configurations however showed some distinctions over the years, as there were lowering of elevations in some of the settlements over the years. In 1967, there were more mountainous areas with elevation range of 240-300 m, forty years after as at 2017, the highlands have been reduced drastically with few settlements being highlands. The lowering of elevation could be because of construction and natural activities as weathering and erosion has changed the topography of the catchment, Olaniyan *et al*, (2015) obtained similar findings. Difference in elevations for the years 1967, 1998 and 2017 is shown in Table 2 to further depict the elevations of selected settlements within the River Ona Catchment. The elevations values of some settlements such as Challenge, Felele, Eleyele, Alaka, Ojoo and Agbowo have changed from elevation range of <240m to <240 m, while some settlements such as Odo-ona, Arapaja, Idi-oro, Ajibode, Dugbe, Yemetu and Mokola however remain unchanged.

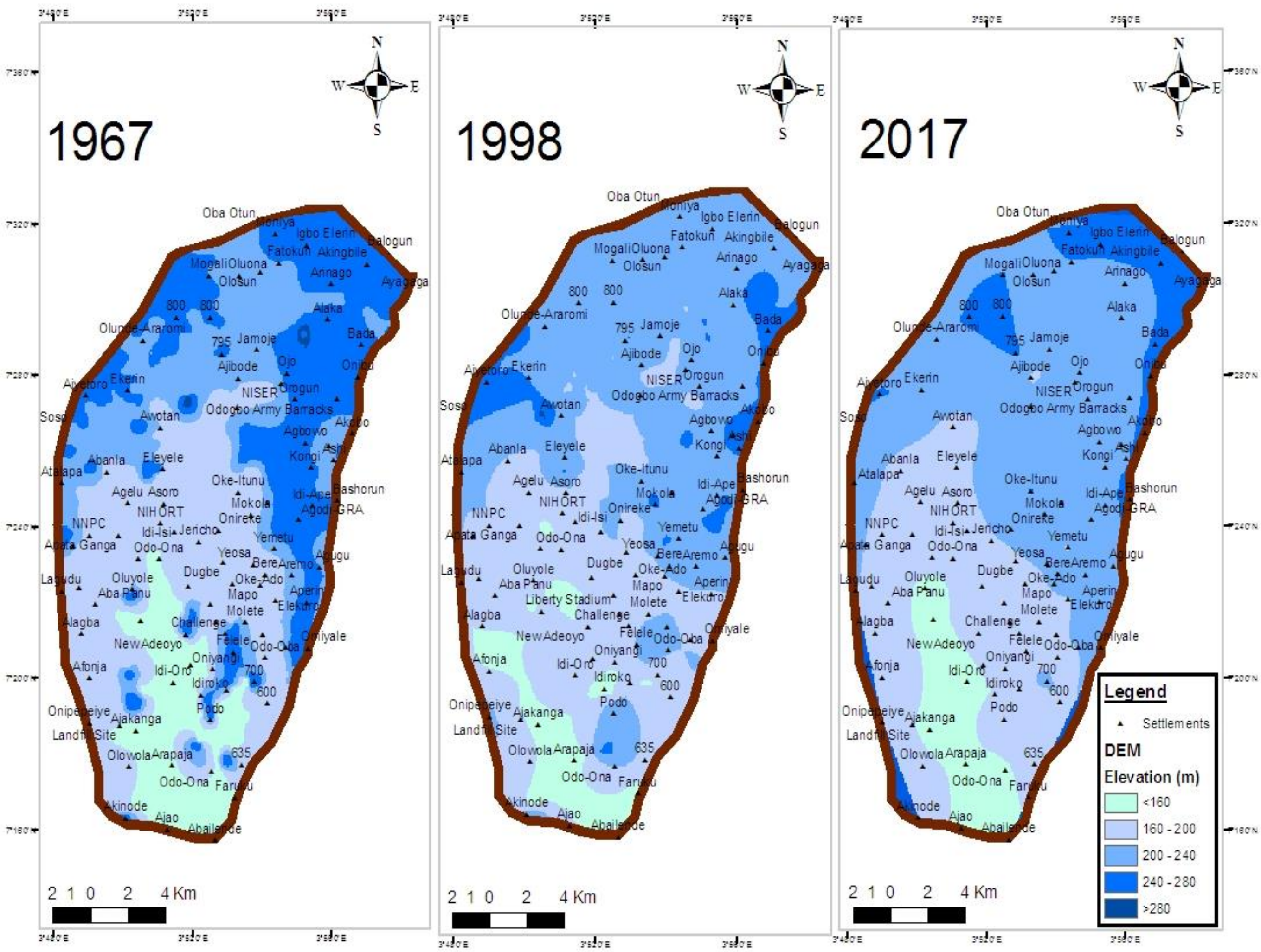

Figure 4: River Ona Digital Elevation Models (DEMs)

Table 2: Elevation Change in Eleyele Catchment

S/N	LOCATION	ELEVATION IN 1967 (m)	ELEVATION IN 1998 (m)	ELEVATION IN 2017 (m)	COMMENTS
1	Agbowo	242	231	230	Decrease
2	Ajibode	240	240	240	No changes
3	Alaka	258	236	238	Decrease
4	Arapaja	142	142	142	No changes
5	Challenge	242	230	228	Decrease
6	Dugbe	168	168	168	No changes
7	Eleyele	241	227	215	Decrease
8	Felele	249	228	214	Decrease
9	Idi-oro	144	144	144	No changes
10	Mokola	188	188	188	No changes
11	Odo-ona	140	140	140	No changes
12	Ojoo	246	232	232	Decrease
13	Yemetu	218	218	218	No changes

Land-use map

The land-use classification map of River Ona Catchment as shown in Figure 5 and the total area covered by the assessed land is 581.79 sqkm. The green part represents the vegetal areas while the black, brown, yellow and blue parts represent the rocky/paved areas, built-up areas, bare lands and water-bodies respectively. The land-use maps show there is a gradual increment in area of lands that are built-up but gradual reduction in the vegetal areas. This is because of urbanization in the Ibadan city, which has increased the dwellers in the city and thereby increment in built-up areas.

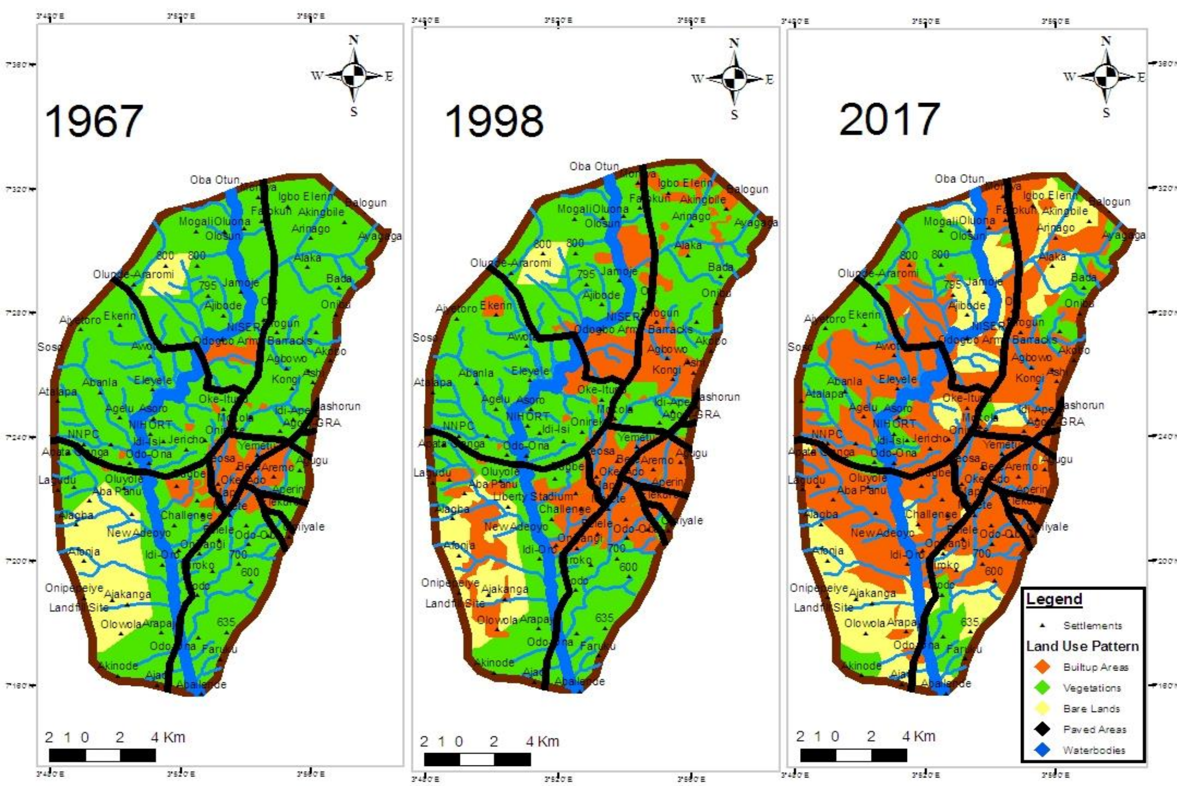

Figure 5: River Ona Land-Use Classification Map

The areas of land use along River Ona for three selected years shown in Tables 3, while Table 4 depicted the changes in land-use pattern of settlements along Ona catchment over the years. The green part are the vegetal areas that covers majority of the assessed area, this is followed by water-bodies, built-up areas and lastly the paved areas. Table 5 showed the area covered by each land-use class. Vegetal areas cover an area of 323.48 sqkm that is 55.6% of the total assessed area. Water-bodies cover an area of 112.29 sqkm that is 19.3% of the total assessed area. Built-up areas cover an area of 102.98sqkm that is 17.7% of the total assessed area. Rocky/Paved areas cover an area of 43.05 sqkm which 7.4% of the total assessed area.

Table 3: River Ona Land-use Area Covered

S/N	Land-use Pattern	TAC in 1967 (%)	TAC in 1998 (%)	TAC in 2017 (%)	Remarks
1	Rocky/Paved Areas	5.2	5.5	5.5	Slight increment in paved areas over the years
2	Vegetal Areas	71.2	56.4	19.1	Drastic reduction in vegetal areas over the years
3	Bare Lands	9.3	6.3	18.3	Undulating increment in bare lands over the years
4	Built-up Areas	8.1	25.5	50.5	Drastic increment in built-up areas over the years
5	Water-bodies	6.2	6.3	6.6	Slight increment in sizes of water-bodies over the years.

Table 4: Change in Land-use Pattern of Selected Settlements in Ona Catchment

S/N	Location	Land use in 1967	Land use in 1998	Land use in 2017	Comments
1	Agbowo	Vegetal	Built-up	Built-up	Land use change pattern over time
2	Ajibode	Vegetal	Vegetal	Bare-land	Land use change pattern over time
3	Alaka	Vegetal	Vegetal	Bare-land	Land use change pattern over time
4	Arapaja	Vegetal	Vegetal	Bare-land	Land use change pattern over time
5	Challenge	Vegetal	Built-up	Built-up	Land use change pattern over time
6	Dugbe	Built-up	Built-up	Built-up	No change over time
7	Eleyele	Water body	Water body	Water body	No change over time
8	Felele	Vegetal	Built-up	Built-up	Land use change pattern over time
9	Idi-oro	Vegetal	Vegetal	Built-up	Land use change pattern over time
10	Mokola	Paved	Paved	Paved	No change over time
11	Odo-ona	Water body	Water body	Water body	No change over time
12	Ojoo	Paved	Paved	Paved	No change over time
13	Yemetu	Built-up	Built-up	Built-up	No change over time

Runoff / Flow Discharge of River Ona

The runoff map of River Ona Catchment over the stretched years is shown in Figure 6. The runoff map depicts the combine effects of rainfall amount, elevation/topography and land-use of River Ona. The runoff in River Ona catchment generally ranges from 60-100cm. These were classified into different levels of severity. The dark green portion represents areas of very low runoff value while the light green, yellow, orange and red potions represent areas of low, moderate, high and severe runoff respectively. The drainage networks in River Ona catchment are generally areas with severe runoff and are floodplain areas. This is because of increase in land development over the years giving rise to replacement of vegetal areas by built-up and paved areas (which have very low water retention) in the catchment. Table 5 shows areas covered by each runoff severity in the three selected years while Table 6 show areas with the runoff severity of selected settlements in the catchment over the years.

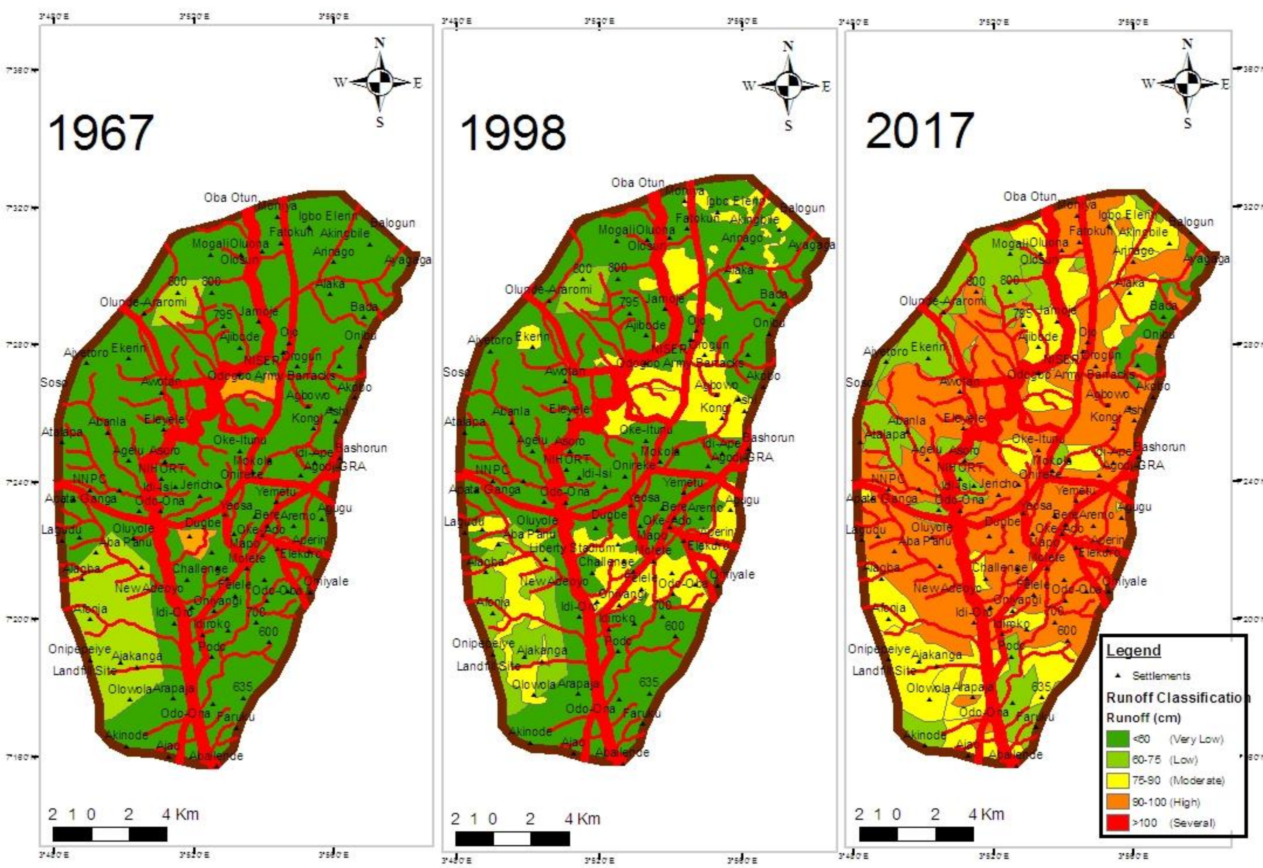

Figure 6: River Ona Runoff Map

Table 5: River Ona runoff severity areas

S/N	Runoff Severity	Total Area Covered in 1967 (%)	1998 (%)	2017 (%)	Remarks
1	Very low	72.1	57.7	3.3	Reduction in very low runoff severity over the years
2	Low	9.7	5.9	14.6	Undulating increment in low runoff severity over the years
3	Moderate	0.3	19.8	20.1	Drastic increment in moderate runoff severity over the years
4	High	3.1	1.5	46.8	Drastic increment in high runoff severity over the years
5	Severe	14.8	15.1	15.2	Slight increment in very high runoff severity over the years.

Table 6: Change in Runoff of Selected Settlements in Ona Catchment

S/N	Location	Runoff In 1967	Runoff In 1998	Runoff In 2017	Comments
1	Agbowo	Very Low	Moderate	High	Land use change pattern over time
2	Ajibode	Very Low	Very Low	Moderate	Land use change pattern over time
3	Alaka	Very Low	Very Low	Moderate	Land use change pattern over time
4	Arapaja	Very Low	Very Low	High	Land use change pattern over time
5	Challenge	Very Low	Very Low	High	Land use change pattern over time
6	Dugbe	Very Low	Very Low	High	No change over time
7	Eleyele	Very High	Very High	Very High	No change over time
8	Felele	Very Low	Moderate	High	Land use change pattern over time
9	Idi-oro	Very Low	Very Low	High	Land use change pattern over time
10	Mokola	Very High	Very High	Very High	No change over time
11	Odo-ona	Very High	Very High	Very High	No change over time
12	Ojoo	Very High	Very High	Very High	No change over time
13	Yemetu	Very High	Very High	Very High	No change over time

Discussions

The effects of climate change seen on River Ona and its catchments are because of larger amount of rainfall and higher mean annual river discharges over the years. The peak rainfall gradient line shows a gradual declination for rainfall over the years that consequently lead to a decrease in the mean annual river discharges. This implies that river discharges increase because of wetter climate. This corresponds well with the results reported for other European catchments (Arnell, 2002). Singh & Bengtsson (2004) and Adeoye *et al.*, (2018) found out that in rainy or wetland areas, increment of precipitation is primarily due to runoff rather than evaporation, because the amount of evaporation is nearly constant due to the already saturated land surface condition. Similarly, the Digital Elevation Model (DEM) showed some distinctions over the years as there was lowering of elevations over the years.

The lowering of the elevations was as a result human activity. Studies by Arnell (2002) Bello *et al*., (2019), Gbadegesin *et al.*, (2020) all stated that the effects of climate change on river discharges in the scenario period would be influenced by changes in land cover and anthropogenic use of water affecting the hydrological system. This will probably increase the actual evapotranspiration, Ea and reduce river discharges from the affected areas (Brooks, 1983; Liu *et al*., 2015). For example, the discharge in 1967 when the vegetal cover was 71.2 % was less than those of the subsequent years when the vegetal areas had declined. This shows that because of the urbanization and increase in population of Ibadan city, there is a reduction in vegetal cover as the vegetation is being replaced by built up areas. In addition, from the study it was discovered that runoff severity tends to increase in area coverage. This was also due to the increase in land development over the years, which have given rise to replacement of vegetal areas by built-up and paved areas thus resulting into very low water retention condition in the catchment. Since the areas have been built up, there is little or no percolation of water since the surfaces are impermeable, hence the low water retention, which often increases the runoff severity.

The rate of annual discharges will increase the width and depth of natural watercourses by increasing erosion according to regime theory (Blench, 1966; Ojo *et al.*, 2018). Therefore, an increase in the mean discharge is seen to exacerbate soil erosion. This leads to loss of soil and may affect nearby farmlands as it is reflected in reduced soil production potential. It could also lead to the damage the drainage networks. It could also increase the fluxes of nonpoint source pollution and sediment to the river channel and this can increase flood frequency and flood risk. Over the years, runoff severity increases and the drainage network in River Ona is severely affected. Most of the drainage areas are flood plains. Higher peak flows would potentially cause more floods, which would have some effect on agriculture and near river; urban areas would experience higher flooding frequency and flood risk. Expansion of urban and paved areas will most likely respond in higher mean annual river discharges and flashier river regimes, because of the quick delivery of rainwater to the river (Arnell, 2002; Otieno *et al.*, 2013 and Adeoye *et al.*, 2018) and as the land use pattern change over time, the runoff increases. Therefore, there is need for preventive measures to be taken to reduce flood risk.

Conclusions

In this study, remote sensing and GIS techniques were used to determine the impact climate change has on the flow discharge of River Ona in Ibadan, Nigeria. The peak rainfall ranges from 84.83-151.29 mm from year 1967-2007. The runoff over the years also had an effect over the land use change pattern over time. It could be concluded that the runoff of River Ona would increase because of wetter climate. The drainage areas in River Ona are always flooded and generally have severe run off. In addition, over the years, runoff severity tends increase. This is because of land development over the years, giving rise to the replacement of vegetal areas by built up areas, which have low retention capacity in the area. The drainage networks should be well monitored and proper and engineered drainage system should be done to drain water away from these areas. In order to reduce river discharge and increase the Ea, the forested or vegetal areas can be doubled to about 20-25% within a tree generation of about 100 years.

References

Adelalu T. G. (2012). Climate variability and River Discharge in Jimeta, Yola Area, Nigeria.

Adeoye, D. O., Ajibola, E. and Ojo, O. I. (2018). Land Use Dynamics Analysis for Sustainable Development Planning Using Geo-Informatics Techniques: Case Study of Ogbomoso Town, Nigeria. *LAUTECH Journal of Engineering and Technology*, 12 (2), 136-148.

Adewale, P. O, Sangodoyin, A. Y. and Adamowski, J. F. (2010). Use of Hec-Ras for Flood Routing in the Ogunpa River in Nigeria. *Journal of Environmental Hydrology,* Paper 25, Volume 18, 2010.

Areola, O. and Akintola, F. O. (1980). Managing the Urban Environment in a Developing country: The Ogunpa River Channelization Scheme in Ibadan city, Nigeria. *Environmental International.* 3:237-241.

Arnell, N. W. (2002). The effect of climate change on hydrological regimes in Europe: a continental perspective. *Global Environmental Change-Human and Policy Dimensions*, 9 (1), 5–23.

Bates, B. C., Kundzewicz, Z. W., Wu, S. and Palutikof, J. P. Eds. (2008). Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

Bello, H. O., Ojo, O. I., and Gbadegesin, A. S. (2019). Land Use/land cover change analysis using Markov-Based model for Eleyele Reservoir. *Journal of Applied Sciences and Environmental Management,* 22 (12): 1917-1924.

Blench, T. (1966). Mobile-Bed Fluviology. University of Alberta Press, Edmonton, Canada.

Brooks, A. (1983). Recommendations Bearing on the Sinuosity of Danish Stream Channels. National Agency of Environmental Protection. Freshwater Laboratory, Silkeborg, Denmark, 326pp.

Coulthard, T. J., Lewin, J., and Macklin, M. G. (2005). Modelling differential catchment response to environmental change, *Geomorphology*, 69, 222–241, 2005.

Gbadegesin, A. S., Bello, H. O. and Ojo O. I. (2020). The Hydraulically Assisted Bathymetry Modeling of Effect Of Weather On Reservoir Water Level, *Acta Technica Corviniensis-Bulletin of Engineering*, 13 (1), 127-132

Intergovernmental Panel on Climate Change (IPCC) (2007). IPCC Fourth Assessment Report AR4. Climate Change: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds. Cambridge University Press, Cambridge, UK.

Lahmer, W., Pfützner, B., and Becker, A. (2001) Assessment of land use and climate change impacts

Liu, B. Z., Yang, D. Q., Ye, B. S., and Berezovskaya, S. (2005). Long-term open-water season stream temperature variations and changes over Lena River Basin in Siberia. Global and Planetary Change 48:96-111.

Mearns, L.O., Hulme, M. Carter, T.R. Leemans, R. Lal, M. and Whetton, P. (2001). Climate scenario development. In: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, J.T.Houghton, Y. Ding, D.J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell & C. A. Johnson (Eds.), Cambridge University Press, Cambridge, UK and New York, NY, pp.739-768. Available for download from: http://www.ipcc.ch (Chapter 13 of the IPCC WG1 Assessment).

Ojo, O. I., Abegunrin, T. P. and Lasisi, M. O. (2018). Application of Remote Sensing (RS) and Geographic Information System (GIS) in Erosion Risk Mapping: Case Study of Oluyole Catchment Area, Ibadan, Nigeria. *Archives of Current Research International*, 1-11

Olaniyan, O. S., Ige, J. A., Akolade, A. S. and Adisa, O. A. (2015). Application of GIS in Water Management of Eleyele Catchment, South-Western Nigeria. *Civil and Environmental Research.* ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online). 7(3), 2015.

Otieno, F. A., Ojo, O. I. and Ochieng, G. M. (2013). Land cover change assessment of Vaal hart's irrigation scheme using multi-temporal satellite data. Archives of Environmental Protection 39 (4).

Singh, P., and Bengtsson, L., (2004). Hydrological sensitivity of a large Himalayan basin to climate change. *Hydrological Processes* 18:2363–2385.

Wurbs, R. A., Muttiah, R. S. and Felden, F. (2005). Incorporation of climate change in water viability modelling. *Journal of hydrologic Engineering*, 10 (5):375-385.