



ANALYSIS OF PATTERN AND EXTENT OF DEFORESTATION IN AKURE FOREST RESERVE, ONDO STATE, NIGERIA

Isaac Adelakun Gbiri^{1*}, Nathaniel Olugbade Adeoye²

¹Department of Geographic Information Systems, Federal School of Surveying (FSS), PMB 1024, 211212 Oyo, Oyo State, Nigeria,

²Department of Geography, Obafemi Awolowo University, PMB 13, 220282 Ile-Ife, Osun State, Nigeria

*Corresponding author, e-mail: isaac.babatunde6@gmail.com

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Abstract

Forest Reserves in Southwestern Nigeria have been threatened by urbanization and anthropogenic activities and the rate of deforestation is not known. This study examined the vegetation characteristics of Akure Forest Reserve using optical remote sensing data. It also assessed the changing pattern in the forest reserve between 1986 and 2017. Global Navigation Satellite System (GNSS) receiver was used to capture the location of the prominent settlements that surrounded the Forest Reserve in order to evaluate their effects on the forest. Landsat TM 1986, Landsat ETM+ 2002 and Landsat OLI_TIRS 2017 with 30m resolution were classified to assess the spatio-temporal changing pattern of the forest reserve. The results showed different composition of vegetation, which include undisturbed forest, secondary regrowth and farmlands. The study further revealed that in 1986, 2002 and 2017, undisturbed forest constituted 63.3%, 32.4% and 32.1% of the entire land area respectively, while secondary regrowth occupied 8.3% in 1986, 9.5% in 2002 and 15.6% in 2017. The farmlands had erratic growth between 1986 and 2017. It was 16.9% in 1986, 22.1% in 2002 and 17.5% in 2017. The bare ground exhibited inconsistency in the coverage. In 1986 the areal extent was 11.5%, when it increased to 36% in 2002 and decreased to 31.9% in 2017. In conclusion, the study revealed the extent of forest depletion at Akure Forest Reserve and it is therefore important that the residents, the government and the researchers show major concern about some of the critical factors to human beings that are responsible for forest depletion.

Keywords: Landsat, deforestation, image classification, Akure Forest Reserve, land use

INTRODUCTION

Establishment of forests began in Nigeria in 1897 with the creation of Woods and Forests for the Colony and Protectorates of Lagos, a year earlier, in 1896 (Schoneveld, 2014). The first forest reserve was created in 1899 under the colonial master, which arose issues of land tenure (Adeyoju, 1975). The Colonial government's initial interest in creating protected areas was to ensure a continuous supply of timbers and other forest resources to the indigenous industries. In the 1900s, the first ever protected area was Olokemeji Reserve and it commenced near Ibadan under the Western State then in 1956. Having seen the benefits derived from the forest, this metamorphosed to the high demand for the establishment of more protected areas (Onokerhoraye, 1985). Spenceley (2015) gave an estimation of 200,000 protected areas in the world, which covered around 15% of the world's land and around 2.8% of the oceans and Nigeria has 960 constituted protected areas which covered a total land area of 10,752,702 hectares representing about 10% of the total land area of 997,936 hectares (Oyebo, 2006). These Protected Areas were subdivided into six categories. It comprised of 1 Strict Nature Reserve, 1 Community forest, 23 Game Reserves, 925 Forest Reserves, 8 National Parks, and 2 Wild Life Sanctuary (FOSA, 2000).

Forests are essential renewable natural resources that have a significant role in preserving environment and serving

as home for all forms of life (Singh et al., 2002; Boyd and Danson, 2005). The Food and Agriculture Organization (FAO) in 1989 pronounced it as home to 300 million people around the world and also contributed to 1.2 billion people living in extreme poverty with women accounting for 70%. FAO (2001) and Singh et al. (2006) described forest as a plant community where the predominant of trees and other woody vegetation with a tree canopy covered more than 10% and area of more than 0.5 ha.

The forests of today have evolved over millions of years. It had been profoundly shaped drastically by swings between warm and cold climates all over the world FAO (2012). The news of last great ice age is ended about 10,000 years ago leaving forests on nearly 6 billion hectares, about 45 percent of the Earth's land area. During the last 10,000 years, cycles of changing climate and temperature had continued to influence the world's forests, while human activities had also increased (FAO, 2012). Fenning and Gershenson (2002) reported that thirty percent of the Earth's land surface area (3.9 billion hectares) forest covers had been depleted from the original forest cover estimated to be six billion hectares while FAO (2010) put current forests cover at about 4 billion hectares, about 31 percent of the Earth's land surface; and over a period of 5,000 years, the cumulative loss of forest land worldwide is estimated at 1.8 billion hectares – an average net loss of 360,000 hectares per year (Williams, 2002). These patterns also applied to other

developing countries in the tropics and sub-tropics. For instance, the East African region lost about 10% of its forest cover to deforestation between 1990 and 2000, with Uganda recording the highest rate (FAO, 2003). In the humid tropical rainforest region of Cameroon, about 200,000 hectares of forest was reported to be degraded annually due to high rate of exploitation (FAO, 2003). And always being an issue of disagreements that it was difficult to make a reliable estimate of the world total forest and local forests, since it depends on the different criteria used to define them then no accuracy measured or consensus in which forest to be measured currently.

In Nigeria, natural forest covered a total land area of 349,278 km² or approximately 35% of the country’s total land mass of 997,936 km² (Nweze, 2002). But about 60% of the country’s forests disappeared between 1850 and 1960 (Morakinyo, 1991). In 1980 alone, forest depleted from 14.9 million hectares to 10.1 million hectares and in 1990 to 1996, it further decreased geometrically to 9.5 million hectares (Federal Department of Forestry, 1997). On the average, it decreased at the rate of 0.4 million hectares per year but the rate of reforestation was put at 0.032 million hectares per year. The forest reserve has also been facing the same effect of this predicament from onset. In Ondo State, 107.36 km² of forest in Ore-Township has been converted to casual land (Adetayo, 2015). Donald (2004) worked on the rich tropical rainforests in many parts of the humid tropics, and the forest disappearing has been attributed to logging and agricultural expansion activities. Butler (2005) stated that Nigeria has the world’s highest rate of deforestation of primary forests, with NEST (1991) documented that at least about (30,000 ha) of forest and natural vegetation were lost annually in Nigeria and this implied that Nigeria has lost 55.7% of its primary forest to logging, subsistence agriculture, collection of fuel wood and other agents between 2000 and 2005 (FAO, 2005). In an attempt to satisfy both local and international need for forest

products and the continuous increase in rural population, forest resources exploitation in this ecosystem is carried out in uncontrolled and unsustainable manners (Onyekwelu et al., 2010). FAO (2005) listed Nigeria as one of the developing countries with very high rate of deforestation and this rate was estimated to be 3% which was not usually consistent. All other woodlands, apart from the constituted areas are regarded as free areas (Adekunle et al., 2013). Both constituted areas and non-constituted areas are almost exhausted for being leading producer of cocoa and timber respectively (Oke and Odebiyi, 2007). However, deforestation had been a major concern for the ministries, government, private individuals, Non-Governmental Organizations (NGOs) and researchers. In an attempt to curb indiscriminate felling of trees or general destruction of forests, Forest Reserves were gazetted across the State. Despite this, Forest reserves continued to shrink in size and area due to pressure mounted from growing populations. In this study satellite images (Landsat TM 1986, Landsat 2002 ETM+ and Landsat 2017 OLI_TIRS) of 30m resolution had been classified to forest vegetal characteristics of Akure Forest Reserve from optical remote sensors and spatial pattern changes were also assessed the in the forest reserve between 1986, 2002 and 2017.

Deforestation conceptual framework: concerning the deforestation in developing countries, an attempt is made to formulate an integrated theoretical framework of the deforestation and forest transition and sustainability theory among others (Yaoqi, 2000). The forecasts and policy suggestions to be presented are argued to be relevant. To analyze deforestation, it is necessary to understand its different causes and sources and adopt a standard for dealing with menace. An approach can be devised to guide the process of identification and analysis of deforestation. A decision point approach was adopted to facilitate this process as shown in (Fig. 1). The framework further

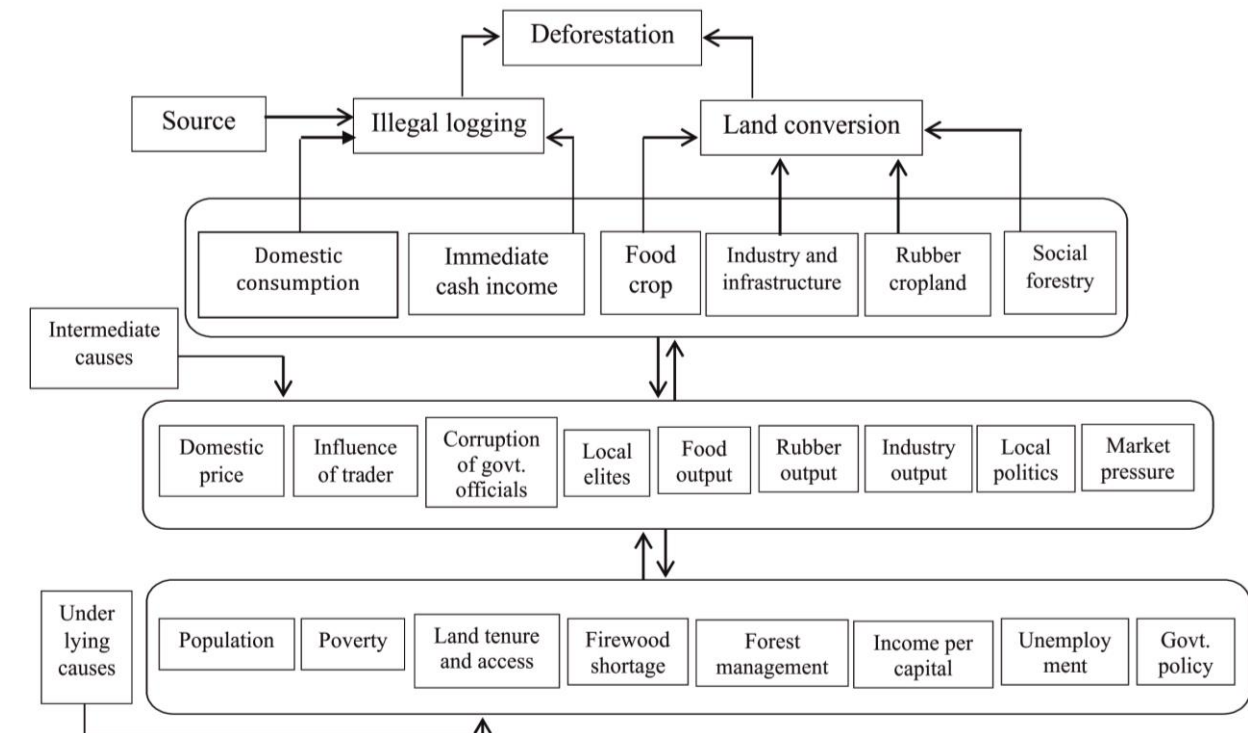


Fig.1 Decision point approach for identification source and causes of deforestation

addresses the identification and classification of different sources and causes of deforestation. It made it necessary to link the analysis to a methodology for the estimation of the extent of potentials of deforestation. The first step was to apportion the deforestation leakage to the different baseline drivers and agents, as they may change with time and space. For example, if the baseline driver was deforestation, but there are two key baseline agents, subsistence farmers and commercial cattle ranchers, the extent to which each contributes to potential leakage may differ over the project lifetime (Louise et al., 2003). The study is therefore examining forest vegetation characteristics at Akure forest reserve from optical remote sensing, assessing the spatial changes in forest between 1986 and 2017, and compare the efficiency of optical remote sensing and normalized difference vegetation index. The factors mapped include land conversion and illegal logging which actually led to the extent of the total area at present status, what are the major anthropogenic activities involved, how much was the levels of encroachment and what was resuscitate steps towards the forest.

STUDY AREA

Akure forest reserve is geographically located in a humid rainforest zone of Akure South Local government area of Ondo State, Nigeria (Fig. 2). It lies between latitudes $7^{\circ}16'$ and $7^{\circ}18'$ N of the Equator and longitudes $5^{\circ}9'$ and $5^{\circ}11'$ E of the Greenwich Meridian. It was constituted as a reserve in 1936 and the total land area covered is 69.93 km². Politically, it lies in Ondo State in Southwestern Nigeria and shares border with Osun State in the Northeast, surrounded by five Local Government Areas in Ondo State namely: Ile Oluji, Oke-Igbo, Ifedore, Akure South, Idanre and Ondo East. Adetula (2002) estimated 11.73% (8.2 km²) cleared for cocoa farming and other food crops, Fuwape et al. (2001) documented the *Gmelina arborea* covered (721.40 m³ and *Nauclea diderrichii* spp (265.18 m³) respectively, Oke (2012) worked on family *Sterculiaceae* including the species counted for 53% of the total tree canopies in the forest, Adejoba et al. (2014) identified hard species as *Strombosi apustulata*, *Celtismild breadi*, *Myrianthus arborea*, or *Khayasene galensis* and *Triplochitons cleroxylon*. Key informants interviewed according to the work of Owusu (2018) affirmed that the loss of vegetation in the city creates livability concerns relating to ecosystem functioning, temperature rise and air quality. He therefore recommended that decision makers should address three critical concerns of resilience, sustainability and livability. The relief pattern is low lying, elevation ranges from 216m to 504m and gently undulating in southern part while the northern part is hilly rock outcrops occurring at close intervals. The underlying rock is crystalline and gneiss. It is slightly neutral; pH of 6.7–7.3 and sandy-loam in nature. The dry season lasts from November to March while the wet season commences from April and ends in October with the highest rainfall records between July and August (Akinseye, 2010), Average daily temperature ranges between 21°C and 29°C almost throughout the year (Adejoba et al., 2014). The mean annual rainfall varies from 2000 mm in southern area to 1500 mm in northern area with relative humidity of 80–85% annually experienced in south-west (NiMET, 2016). Aponmu and

Owena Yoruba speaking communities owned the forest, though, it also had minor settlements surrounding the forest. They include Ipogun, Kajola/ Aponmu, Kajola, Ago Petesi, Akika Camp, Owena Town, Ibutitan/Ilaro Camp, Elemo Igbara Oke Camp and Owena Water new Dam.

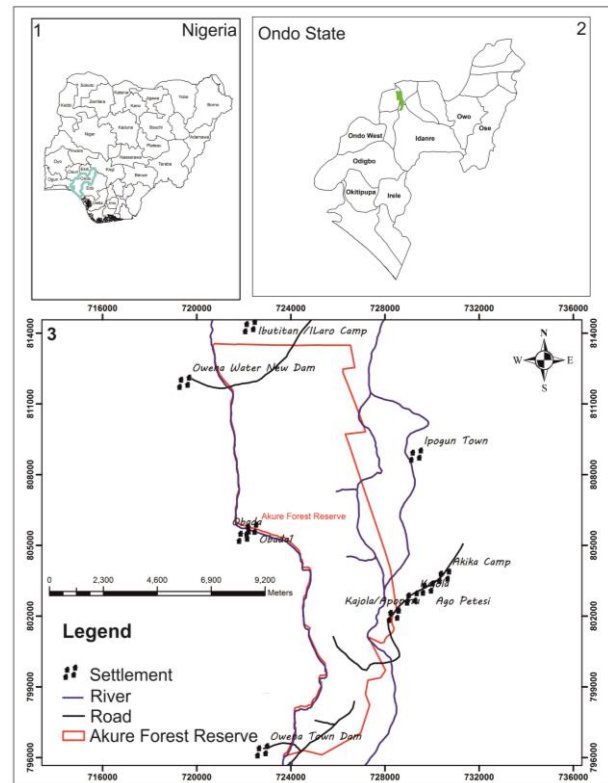


Fig. 2 Overview of Akure Forest Reserve

DATA

Spatial coordinates of prominent settlements in the Akure Forest Reserve (AFR) were captured as points with Garmin eTrex20 Global Positioning System (GPS) device. Topographic map (1:250,000) was sourced from the Office of Surveyor-General of the Federation (OSGOF), Abuja. The map was scanned through A0 scanner. The map was georeferenced with grid coordinates on the map through ArcGIS 10.3 and it was used to exact boundary of Akure forest reserve and other important features in the forest reserve such as, the road networks that are within the forest for accessibility was updated via open street map. The river network in the study area was extracted because the two major rivers flow through the forest forming the forest reserve boundary and the root means square error was 0.5 for the spatial accuracy. The survey plan (1:5000) was sourced from the Ministry of Natural Resources, Alagbaka, Akure, Ondo State. The plan was scanned using an A4 flatbed scanner. It was imported into the computer and georeferenced with grid coordinates on the survey plan using ArcGIS 10.3. Boundary was also extracted which was more accurate than the one from Topographical map and it was used for boundary extent and images subset as well. The existing topographical map and survey plan were referred as the base maps in the study. Landsat, a U.S developed series of platforms operated by Earth Observation Satellite Company (EOSAT) are the most common satellite systems for large area data acquisition. The

satellites sensors offer broad area of coverage, and for instance Thematic Mapper (TM) sensor covers 165 x 180 km with temporal resolution of 16 days, six bands with spatial resolution of 30 m (blue, 0.45 to 0.52 μ m; green, 0.52 to 0.60 μ m; red, 0.63 to 0.69 μ m; near infrared, 0.76 to 0.90, μ m; mid infrared, 1.55 to 1.75 μ m; and mid infrared, 2.08 to 2.35 μ m) and one band with spatial resolution of 120m (thermal infrared, 10.4-12.5 μ m). Landsat Enhanced Thematic Mapper Plus (ETM+) sensor covers 170-183 km with temporal resolution of 16 days, bands 1-5 and 7 contain spatial resolution of 30meter. The resolution for Band 8 (panchromatic) is 15 meters (blue, 0.45-0.52 μ m; green, 0.52-0.60 μ m; red, 0.63-0.69 μ m; near infrared, 0.7-0.90, μ m; shortwave infrared (SWIR) (1) 1.55-1.75 μ m; Thermal, 10.40-12.50 μ m; Shortwave Infrared (SWIR) (2) 2.09-2.35 μ m and Panchromatic band has a spatial resolution of 15 meter (0.52-0.90 μ m). Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) sensor covers 170 x 183 km temporal resolution of 16 days. It consists of nine spectral bands with a spatial resolution of 30 meters, for bands 1 to 7 and 9. The ultra-blue band 1 is useful for coastal and aerosol studies. Band 9 is useful for cirrus cloud detection. The resolution for band 8 (panchromatic) is 15 meters. Thermal bands 10 and 11 are useful in providing more accurate surface temperatures, Ultra Blue (coastal/aerosol) 0.435-0.451 μ m; blue 0.452-0.512 μ m; green 0.533-0.590 μ m; red 0.636-0.673 μ m; near Infrared (NIR) 0.851 - 0.879 μ m; Shortwave Infrared (SWIR) (1) 1.566-1.651 30 μ m; shortwave Infrared (SWIR) (2) 2.107-2.294 μ m; Panchromatic 0.503-0.676 μ m; Cirrus 1.363-1.384 μ m; thermal Infrared (TIRS) (1) 10.60-11.19 μ m; and Thermal Infrared (TIRS) (2) 11.50-12.51 μ m. (Both systems are in Sun synchronous orbits so the satellite passes over the same area of the earth at the same solar time in each temporal cycle. The Landsat TM 1986, Landsat 2002 ETM+ and Landsat 2017 OLI-TIRS of 30m resolution and each was captured in June. The land use/ cover classification systems were adopted for the study. The land use/cover product is classified into five land cover classes; undisturbed forest, farmland, secondary regrowth, bare ground and water body. The study used Landsat data to carry out change evaluation of forest vegetation characteristics and assessed the spatial pattern changes in the forest reserve between 1986, 2002 and 2017. Table 1 describes merely the secondary data with their parameters which include satellite data and existing data of Topographical map and survey plan used.

Table 1 Parameter of the datasets for the study

S/ N	Data Type	Acquisition date	Swath (km)	Path/ Row	Spat. res. (m)
1	Landsat TM	19/6/1986	185	190/55	30
2	Landsat ETM+	19/6/2002	185	190/55	30
3	Landsat OLI/TIRS	20/6/2017	185	190/55	30
4	Topographical map	6/6/1986	-	-	1:250,000
5	Survey plan	15/12/2009	-	-	1:5000

METHODOLOGY

The methodology was summarized in the workflow of the data processing (Fig. 3). Data analyses, compilation and raster statistics were generated in both Erdas Imagine and ArcGIS 10.3. Statistical analysis and investigation of possible trends were carried in Microsoft Excel as well. Pre-processing of satellite data was required and Normalized Difference Vegetation Index (NDVI) was also engaged and analyzed for the study. Satellite data was sourced through Path 190/Row 055 and downloaded from Global Land Cover Facilities (GLCF), United States Geological Survey (USGS) in digital format into the computer via earth explorer window and then it was imported into Erdas Imagine 9.2 version through classic viewer.

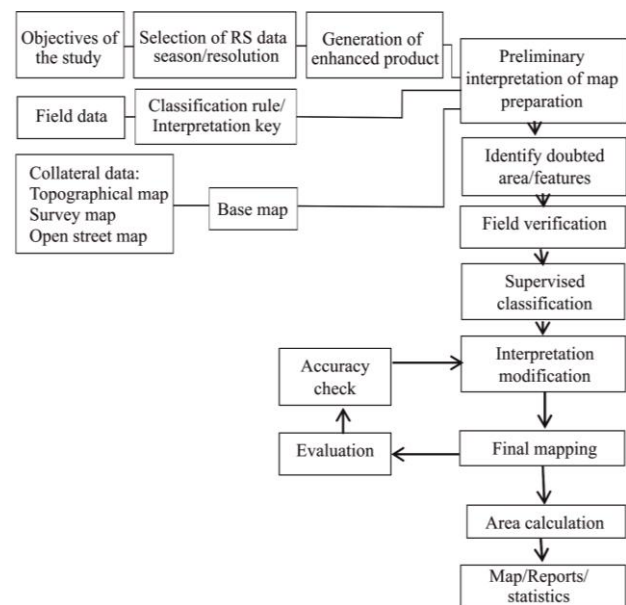


Fig. 3 Workflow of data processing

The images noise was filtered through radiometric enhancement as shown in (Fig. 4). The visual image interpretation and digital image processing combined with aid of creating layer stacking from the images the useful Landsat manual guide was used to produce natural colour for the satellite data and sub-map creation of raster data was done from the boundary extracted survey plan. The pre-processing of layer-stacking were carried out intensively for proper accountability of Ortho-rectification of the satellite images. The image was then processed in Erdas Imagine software. The satellite image of each band was stacked. Then, from the stacked satellite image the study area image was extracted by masking in ArcGIS 10.3 software. Supervised classification was used and where the user develops the spectral signatures of known categories to extract phenomena by assigning each pixel in the image to the cover type to which its signature is most comparable. It is of interesting to know that area of interest (AOI) which also known as training classes were used to represent a particular class.

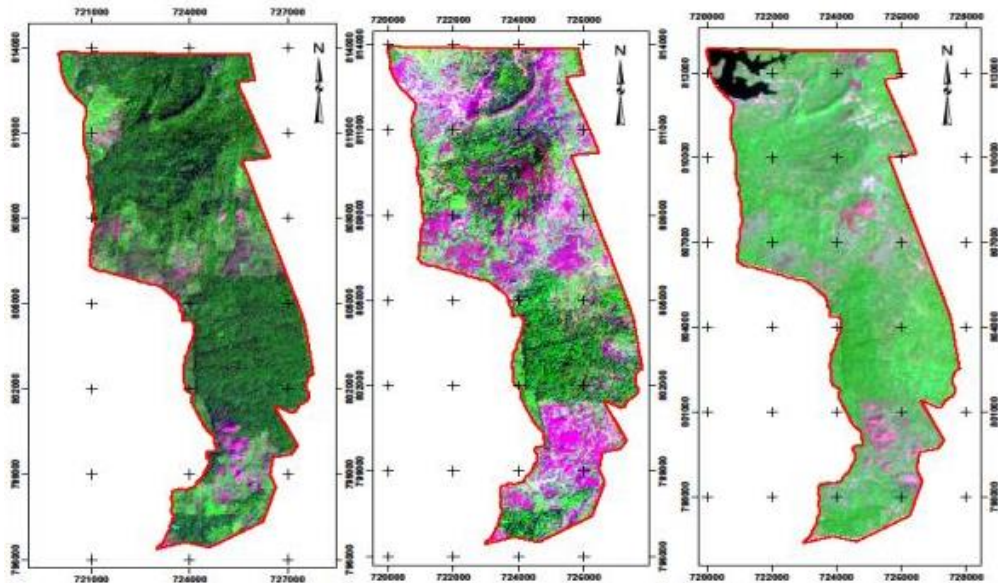


Fig. 4 Enhanced Landsat imageries 1986, 2002 and 2017 RGB: 321, 753 and 654

Basically it follows the operational order of: defining of training sites, extraction of signatures and classification of the image (Supervised classification) then during the supervised classification process, the entire Signature editor was selected and it was used on the classification process. The pattern of land use type, ground truthing and personal experience were considered as the 3 major advantages to analyze the remotely sensed data. The classes were defined by the difference in their physical attribute and characteristics by considering the option of maximum of likelihood method which possessed the capability of taking care of similar features in the study area. The ground truthing was also employed by blowing up the image pixel and obtained the coordinates and pre-loaded these coordinate on the GPS device for the verification of the features in the study area in (Fig 5).

It was conducted based on area frame sampling where the basic unit referred as segment. It was carried out in early march 2017. A systematic random sampling method was adopted for collecting sample points of samples segment. Systematic random sampling enabled the samples be distributed evenly to all parts of the study. The size of sample segment is 1 km by 1 km and sample size is 0.5 km by 0.5km. A total of 47 segments were selected and 71 sampling points were collected, where each sample has two samplings and it further enhanced the authentication of the forest and it was subdivided into equal portions. The second approach is to calculate of the Normalized Differenced Vegetation Index (NDVI). This index is the difference of the near infrared (NIR) and the red band divided by their sum ($NDVI = \frac{NIR-RED}{NIR+RED}$) which usually revealed areas that have high reflectance in the near infrared. Data post-processing which included checking pixel reliability and separability, producer, users, omission error, commission error and overall accuracy were also adopted for the analyses. Accuracy assessment reflects the real difference between classification and the reference data from the mapper by considering the rows (classes as mapped) and columns (classes as found in the field) and this has become more important than ever (Congalton, 1991). In our study the results of the percentage accuracy of the producers and users for each class names, reference total, classified total and number of pixels corrected and with their overall accuracy were described for 1986, 2002 and 2017. Remotely-sensed spectral data is a continuous form of data where digital numbers (dn) represent the reflected energy in each band (spectral region). The focus of image classification is to assign each cell or picture element (pixel) of the satellite digital data into an appropriate thematic category in a process called "discrete classification." The most common data clustering algorithm used was maximum likelihood and Other types of data clustering algorithms. The decision rules for the supervised classification process are multi-level: non-parametric and parametric. For parametric signatures, it comprises of: maximum likelihood, Mahalanobis distance

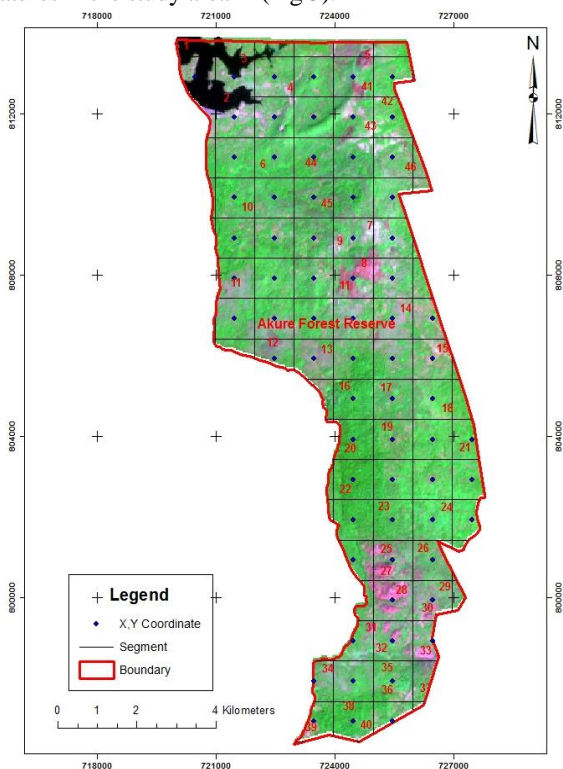


Fig. 5 Area frame sampling of Akure Forest Reserve RGB: 654

and minimum distance. Parametric Rule was used and it defines classified pixels that fall into the overlap region where pixel is tested against the overlapping signatures only and whenever it reveals that neither of these signatures is parametric, then the pixel be given unclassified. But then, if only one of the signatures is parametric, then the pixel is automatically assigned to that signature's class. The maximum likelihood decision rule is based on the probability that a pixel belongs to a particular class. It assumes that these probabilities are equal for all classes, and that the input bands have normal distributions and it had capability of taken care of all similar phenomena.

Land use depictions become strong option to this study. It arranges human conceptualization of true picture of the reality i.e. how the view of reality usually being represented in a simplified manner that still satisfy the information requirement for study at hand without being distorted. Here are the basic entities used in the Land use classification schemes are described as follow: Undisturbed Forest describes deep dark green tree with which includes with other trees of similar spectral signatures and it is usually computed and represented in polygon; Bare ground includes Lands with exposed soil, sand or rocks, and never has more than 10% vegetated cover at any time of the year; Secondary regrowth describes light green tree with spectral response; Water Body describes Lakes, reservoirs, stream, rivers, and swamps and Farmland describes as tree crops and enclaves found within the forest. Therefore, the quality control of the pixels was verified on the land use and all were found above the average. The analyzed spatial change assessment was generated and it was used to compare the areas covered for the study. Meanwhile, time series of NDVI generation was subjected to the health

status of the forest and also taking the average index over the complete study area, by allowing the comparison between years to examine.

The Normalized Difference Vegetation Index (NDVI) had been known for its capability of monitor the health of the vegetation. Both red and near infrared bands was adopted for this analysis This model has been extensively used to monitor drought, monitor and predict agricultural products, assist in predicting hazard fire zone and map desert encroachment (Lillesand et al., 2004). The model formula was given below mathematically by Rouse et al. (1974).

$$NDVI = \frac{P_{NIR} - P_{RED}}{P_{NIR} + P_{RED}} \tag{1}$$

Pettorelli et al. (2005a) explained the concept behind NDVI that for vegetated surface, red (PRED) and near infrared (PNIR) wavelengths are characterized by high and low absorption respectively. The index output value range the greenness from -1 and 1 Negative values shows the presence of cloud water and snow while zero values form basis for rock and bare soil, moderate values such as 0.2 to 0.3 represents the shrub and grassland while high values such as 0.6 to 1.0 indicate the temperate and Tropical rainforest in accordance with work done by (Lillesand, 2004). In 1986, it was revealed in Figure 6 that -0.4 to 0.4 indicates the presence of water body, rock and the scattered tropical forest in the forest. In 2002, it revealed -0.4 to 0.08 which shows that the scattered tropical forests are no longer seen again as seen before. In 2017, it ranged from -0.4 to 0.3 which shows the presence of water, rock formation, tree canopies and the tropical forest recovered little from the shocked of consumers. The overall result indicated that there were moderate shrubs and grassland, fewer temperate and tropical rainforest in the reserve.

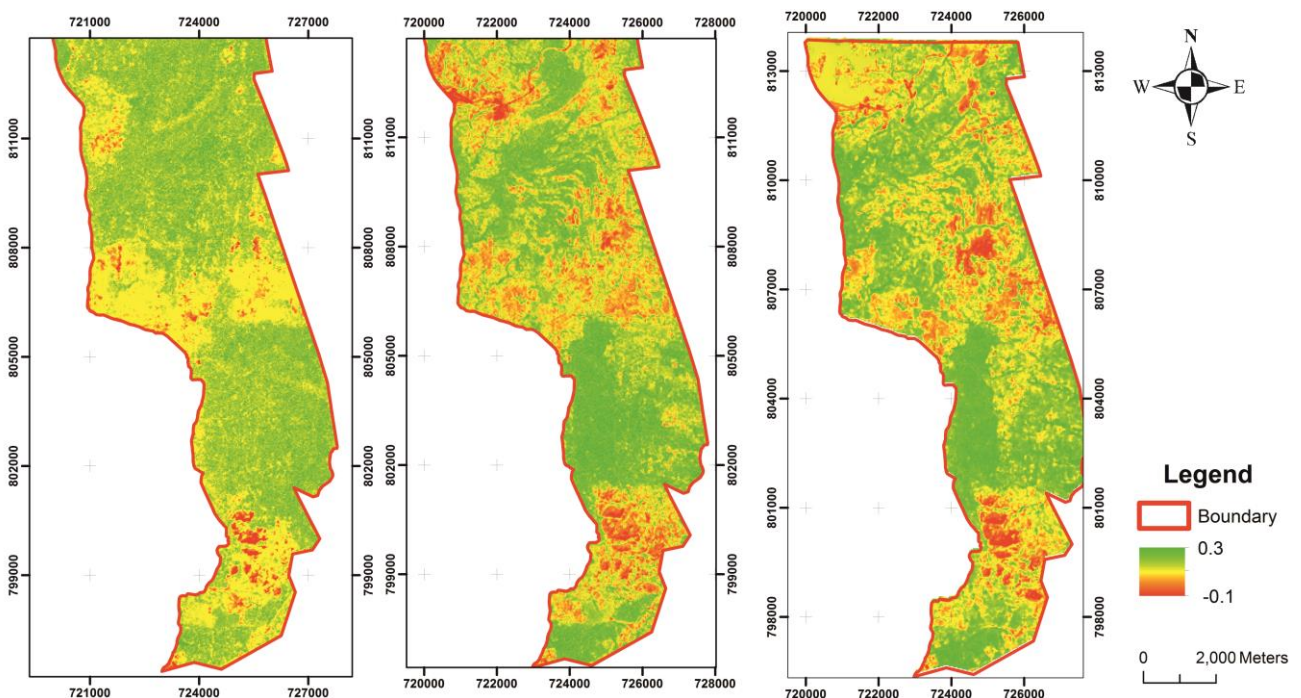


Fig 6 Normalized Difference Vegetation Index of 1986, 2002 and 2017

RESULTS

The entire study area covered 69.93 km² which was tuned to about 7139.8 hectares of forest land. The undisturbed forest was characterized as deep dark green tree in 1986 represents the total area of 4520.7 hectares (63.3%) of the whole study area, Bare ground covered, 818.1 hectare (11.5%), Farmland occupied 1209.9 hectares (16.9%), Secondary regrowth forest covered 590.9 hectares (8.3%) and water body as well covered the tune of 207.900 hectares which represents 2.9 % of the forest. These were so even before the forest was constituted as a reserve in 1936. In 2002, bare ground was increased by covering 2573 hectares represents (36 %) as against (11.5%) of 1986, Farmland increased by 1575.3 hectares (22.1%) as against 16.9%, Secondary regrowth increased by 590.993 hectares (9.5%) against 8.3%, Undisturbed forest decreased gradually to 2311.3 hectares (32.4%) as against 63.3% increased previously. In 2017, bare ground represented 2274.4 hectares (31.9%) reduced by 4.1% in five year of the study, the Farmland also covered 1249.470 hectares (17.5%), undisturbed forest decreased

further to 2289.900 hectares (32.1%), Secondary regrowth covered 1118.070 hectares (15.6%), while water body covered 207.900 hectares (2.9 %) emerges openly due to human factors being seen all over places in Table 2 and that summarized patterns of land use in details for 1986, 2002 and 2017. Figure 7 quantified amount of alterations influenced by the humans. While making compare of 1986, 2002 and 2016 land use change, it was discovered that the depletion around Obada, Owena and Ibutitan/Ilaro camp induced by the influence of human factors due to direct access. Vegetation was more seen in 1986 but unlike 2002 and 2017. Water body was not also revealed in the data of 1986 and 2002 but there the indication of riparian forest was seen on satellite image. Owena river that formed the bases of natural boundary of the forest was dredged for the purpose of dam construction. It was resulted into emergency of water body revealed on the image of 2017.

Figure 8 presents the proportion of land use categories of 1986, 2002 and 2017 in distinct multiple charts. It is vital to compare between green cover areas and areas are subjected to changes in proportions since it answered to when, how or

Table 2 Compositions of land use of Akure Forest Reserve in 1986, 2002 and 2017

Land use classes	Landsat TM 1986		Landsat ETM+ 2002		% change 1986-2002	Landsat OLI 2017		% change 2002-2017
	Area [ha]	Area [%]	Area [ha]	Area [%]		Area [ha]	Area [%]	
Undisturbed Forest	4520.7	63.3	2311.3	32.4	-30.9	2289.9	32.1	-0.3
Farmland	1209.9	16.9	1575.3	22.1	5.2	1249.4	17.5	-4.6
Bare Ground	818.1	11.5	2573.0	36	24.5	2274.4	31.9	-4.1
Secondary Regrowth	590.9	8.3	679.9	9.5	1.2	1118.0	15.6	6.1
Waterbody	-	-	-	-	-	207.90	2.9	2.9
Total	7139.8	100	7139.8	100	0	7139.8	100	0

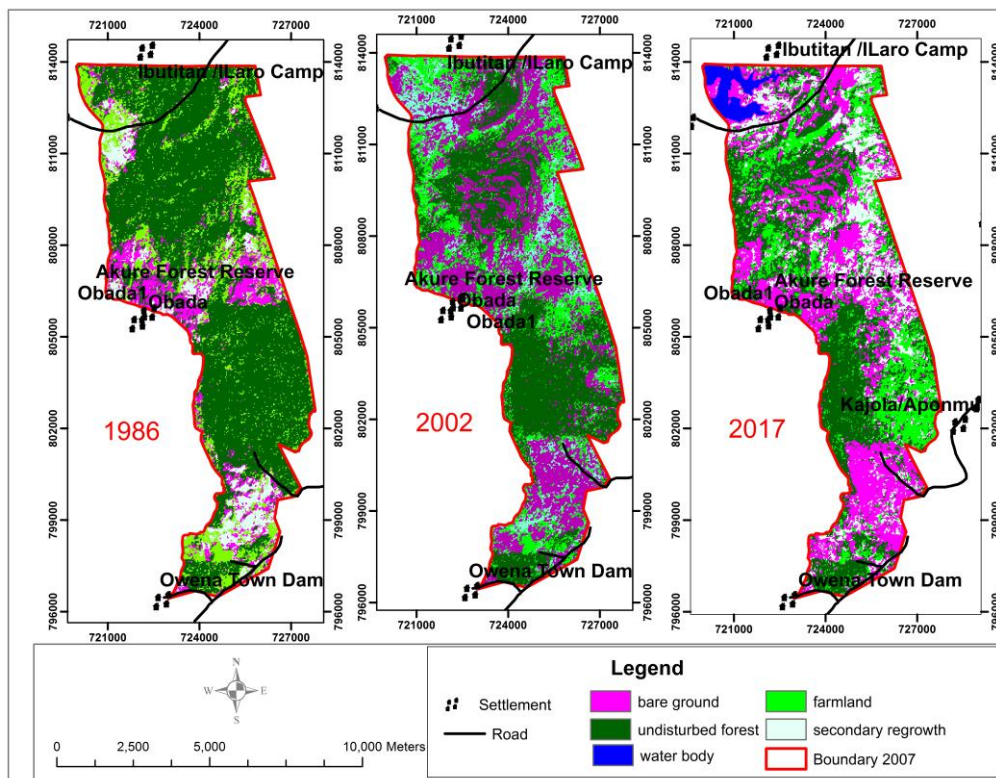


Fig. 7 Patterns of land use in 1986, 2002 and 2017

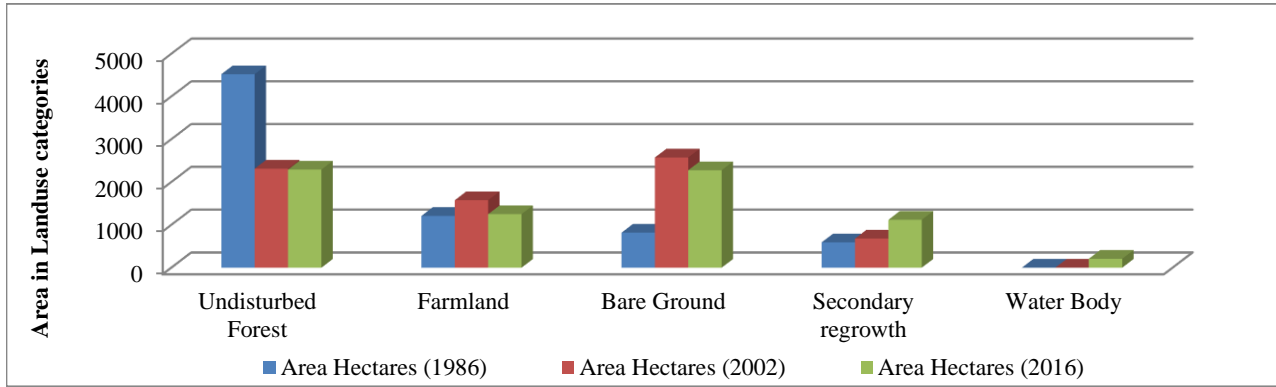


Fig 8 Proportion of land use categories in 1986, 2002, and 2017

why the forest had changed from time without numbers. In 1986, 63.3% of the area was considered as vegetated areas, this decreased to 32.4% in 2002, and it was almost half of undisturbed forest had been altered over a period of sixteen years which was hugged. In fifteen years later, it was reduced to 32.1%, the reduction accounted for variation of 0.3% in 2017 which was no pronounced as it were in 1986 to 2002. The reduction is not significant as results of interference by the concerned authority of the forest in 2017. Farmland in 1986 was computed as 16.9%, it increased 22.1%, in 2002, in 2017, it was 17.5% which decreased by 4.6%. Bare ground in 1986 was 11.5%, in 2002, it significantly inclined to 36%, in 2017, it was 31.9%, in 1986, Secondary regrowth tends to increase from 8.3% - 9.5% for the period of sixteen years and later increased to 15.6% in 2017. This increased showed that there was interference of the concerned authority along the line to improve the forest by reintroducing seedlings to the settlers found around the forest. At emergence of water body, it accounted for 2.9% of the total area of the study.

The rate at which undisturbed forest reduced in forest between 1986 and 2002 was shown vividly in Table 2. It decreased by about 3.1% per annum and reached the peak around the year 2002. By this year, the forest area had recorded roughly at about 30.9% of the forest that was left under undisturbed forest. Between 2002 and 2017 the rate of vegetation reduction was close to negligible. It was as low as 0.3% which suggests that there were very little open forests to be altered and converted to other land uses. The farmland reduction in 2002 drastically as results of cocoa and banana plantations people around the forest had been practicing in the area. In 2017, also it shows that there was conversion of 4.6% which implies there conversion of more forest than in 1986, but slightly drops from the figures recorded in 2002. Large conversion of forest into other land uses, including bare ground has significant implications, which could be best explained by its settlers round the forest. In 2002, it was 36% of the total forest which had doubled up of what actually recorded in 1986. In 2017, the increased drop by 4.1% in fifteen years later. Secondary regrowth tends to improve by the initiate being put place by concerned authority for the period of last sixteen years. The water body emerges due to alteration of the river that formed the boundary for the forest. The study also focuses on the option of integrated ground truthing measured to authenticate the reality on the ground. Accuracy assessment reflects the real difference between classification and the

reference data from the mapper by considering the rows (classes as mapped) and columns (classes as found in the field) and these had become more important than ever as it shown in Tables 3, 4 and 5. Reference data believes to be accurate and it reflects the true land use. It had a sources which include, ground truth, higher resolution satellite images and maps derived from aerial photo interpretation while number correct denote software correction after classification. The overall accuracy of the classified image compares how each of the pixels classified versus the actual land cover conditions obtained from their corresponding ground truth data and it considers all off-diagonals together as classification failures.

Table 3 Accuracy assessment pattern of 1986

Class Name	Reference Total	Classified Total	Number Correct	Producers Accuracy	Users Accuracy
Undisturbed forest	173	194	159	91.91%	81.96%
Farmland	54	38	37	68.52%	97.37%
Bare ground	44	30	28	63.64%	93.33%
Secondary regrowth	26	14	13	50.00%	92.86%
Total	297	276	237		

*Overall Classification Accuracy (86.72%) * Overall Kappa Statistics (0.804)

Table 4 Accuracy assessment pattern of 2002

Class Name	Reference Total	Classified Total	Number Correct	Producers Accuracy	Users Accuracy
Undisturbed forest	18	39	16	88.89%	41.03%
Farmland	21	10	6	28.57%	60.00%
Bare ground	65	63	51	78.46%	80.95%
Secondary regrowth	30	12	10	33.33%	83.33%
Total	134	124	83		

* Overall Classification Accuracy (77.34%) *Overall Kappa Statistics (0.675)

Table 5 Accuracy assessment pattern of 2017

Class Name	Reference Total	Classified Total	Number Correct	Producers Accuracy	Users Accuracy
Undisturbed forest	54	45	40	74.07%	88.89%
Farmland	37	25	21	56.76%	84.00%
Bare ground	67	46	36	53.73%	78.26%
Secondary regrowth	15	15	11	73.33%	73.33%
Water	9	2	2	22.22%	100.00%
Total	182	133	110		

*Overall Classification Accuracy (71.05%) *Overall Kappa Statistics (0.675)

This further expressed some of human and environment factors which have contributed to the forest depletion. The factors concern includes the rising of logging, the frequency and severity of water over bank which sometimes falls most of tall trees because it was rivers the formed the natural boundary of the forest, cattle herders and fire. Although, these were views being seen during the data acquisition and they merely facts to reckon with Table 6 presents the trend of various land use for 1986, 2002 and 2017 as it shown below and it was explained further by displaying the rate change (%) in the two investigated periods (1986-2002 and 2002-2017).

Table 6 Rate change (%) in the two investigated periods (1986-2002 and 2002-2017)

Land use	Rate of change (%) 1986-2002	Rate of change (%) 2002-2017
Undisturbed Forest	-30.9	-0.3
Farmland	+5.2	-4.6
Bare Ground	+24.5	-4.1
Secondary regrowth	+1.2	+6.1
Water Body	-	+2.9

DISCUSSION

The important concepts of forest cannot be overemphasized because it was spatially distributed across the surface of the earth and by offering the potential values to the dynamism of local, regional and global ecosystem processes. It needs to be protected, monitored for conservation and sustainable management at all time. Mostly, Forests are important globally for provision of fibers to meet human needs, from local uses such as cooking fuel through to industrial utilization for construction materials. Although, land use has been extensively analyzed by the researchers in the past through the aid of satellite data and they had been achieved greatly. In this study, it has been proven, that the supervised classification of multi temporal satellite images were more effective tool to quantify and detect changes/alteration of environment which were shown in Figure 7. However, it

indicated that bare ground, farmland and secondary regrowth in the area have increased tremendously, to possibly support population growth of the surrounding settlements or influx of loggers often coming from the cities. With this evidence, one can actually submit that most of undisturbed forest had been converted to bare ground and farmland since it is obvious that undisturbed forest was at pace of reduction yearly and it was equally shown on the image while the secondary regrowth is gaining its popular expansion as well as others. NDVI is useful for checking the health of the reserve and to compliment the various categories of the spatial change patterns derived from the Landsat. Additionally, it is also important to adopt ground truthing approach as it was shown in Figure 5 to authenticate the exact feature on the ground as it is against the final classification for clarification and this was a little bit difficult but it was later successful. It was extensively discussed in Tables 2, 3 and 4 describe the accuracy of classified image which had been proven important and that serves as of authenticity for any image used (Aronoff, 1958). The post classification required since the final accuracy of image depends on the accuracy of the independently classified images (Yuan et al., 2005). This was done by using the accuracy assessment module in Erdas Imagine. The results in Table 6 tend more than enough to permit its use for further analysis. Another way of identifying change within the study area is by using the Kappa Index of Agreement (KIA) which ranges from -1 to 1 and study findings were 0.8047 (in 1986 image), 0.6753 (in 2002 image) and 0.6138 (in 2017 image) and the results supported the statement attributed by Congalton and Green (1999) that overall change occurred by chance, then K equals zero (K= 0). That means changes have taken place in both classified data. Most often conversion of the reserve to farmland had improved their quality life and behavioural pattern of the dwellers in the settlements by making their ends from the forest because they have known for cocoa farming as their major occupation especially those dwellers in the suburb. And to the authority, it contributes to the sustainable development of ecosystems and provision of ecological range and social benefits had been deeply threatened due to the quest of getting resources out of the forest. It is expected that the authority concerns control the abundance and biodiversity of the forest and take the responsibility by ensure protection and others.

CONCLUSION

Forest vegetation characteristics and spatial pattern changes in the Akure Forest Reserve between 1986, 2002 and 2017 were successfully observed by obtaining Landsat images. The data analysis shows that forest has lost almost all the vegetation cover. It's just leaving about 32.1% of undisturbed forest as at 2017 while other land uses are increased yearly. The critical part of the reserve loss occurred between 1986 and 2002. These indicate that the spatial distribution pattern of bare ground had increased geometrically due to interferences of the settlers that surrounded the reserve and farmland also increased due the conversion of forest to cocoa plantations. Consequently, the reserve had been threatened due to anthropogenic activities of man while the vegetation of secondary

regrowth, farmland, and bare ground began to increase and the vegetation being known within the reserve which characterized by hard species noticed no more. Interestingly, the period was characterized by conversions including farmland and among others. This study recommends that for Akure forest authority to address problems relating to conversions of forest there is the need to take critical look at the forest policies plans and its implementation which can provide quick answered to some of intermediate and underlay causes of forest conversion. The past three decades saw that there is a shift to revitalize some of our forest from the hands of loggers and others. This pattern had been helpful and it must be focused on it if forest in Akure needs sustainability. However, it's erroneous difficult in achieving these recommendations in conceptual frame work due to changes in policy most often.

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ENVIRONMENTAL STATUS OF A CITY BASED ON HEAVY METAL CONTENT OF THE TREE-RINGS OF URBAN TREES: CASE STUDY AT SZEGED, HUNGARY

Tímea Kiss^{*}, István Fekete, Ibolya Tápai

Department of Physical Geography and Geoinformatics, University of Szeged, Egyetem u. 2-6., H-6722 Szeged, Hungary

^{*}Corresponding author, e-mail: kisstimi@gmail.com

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Abstract

Urban vegetation, especially urban trees could act as ecological archives, as they reflect various elements of their environment. The main aim of the study is to evaluate the spatial and temporal variations of environmental conditions in the city of Szeged (Hungary) based on long-term monitoring of the heavy metal content of tree-rings (soft wood). In general, the living conditions of the urban trees (and other organisms as well) at Szeged was the worst in 2001/05, when the heavy metal pollution was the greatest, therefore the biomass production of the sampled trees decreased. Fortunately, the environmental conditions became better, only there are some points in the industrial area, where the heavy metal pollution of the environment is gradually increases. The temporal change in lead pollution (considerable decline in 2013/17) could be explained by the obligatory usage of lead-free petrol since 1999 and the diversion of through-traffic from the town (2011). The introduction of unleaded petrol had delayed favourable results, as the dust particles containing lead probably circulated in the air for a while before they were gradually become fixed in the soil or they were washed out from the town during heavy rains. The cadmium pollution also declined after the traffic diversion, as it is connected to the usage of brake-linings. Whilst the lead and cadmium content of the tree-rings decreased during the studied decades, the trees accumulated increasing amount of zinc throughout the studied periods, as this element could be up-taken from the ground-water, as the larger the canopy of a tree the denser and deeper its root system is.

Keywords: heavy metal, pollution, urban vegetation, environmental stress, long-term monitoring

INTRODUCTION

Urban vegetation is exposed to various noxious environmental effects, especially along busy roads. The most important disturbances are related to (1) increased air and soil pollution in connection to traffic and heating; (2) compaction and burial of soils, which decrease the water availability and impede the transpiration of the root-system; (3) mechanical injuries; (4) extreme water-household and temperature conditions in connection to urban heat-island and built-in areas; and (5) extra salt input into soils linked to defrosting of roads during winter (Gulyás and Kiss, 2007). These disturbances are usually overlapped aggrading each-other's effects, and leading to growth irregularities and water-household imbalances (Ballach et al., 1998). At the same time the state of the urban vegetation reflects the environmental status of an area, which is related to the social, economic, cultural and health status of an urban neighbourhood (Lányi, 2000). Urban vegetation, especially urban trees could act as ecological archives, as they reflect various elements of their environment (Alestalo, 1971; Kern and Popa, 2009), therefore they could be used to map the environmental status of urban areas and to identify those neighbourhoods which are more prone to environmental load.

The main aim of the study is to evaluate the spatial and temporal variations of environmental conditions in the city of Szeged (Hungary) based on the heavy metal content of tree-rings (soft wood). In the frame of the

research we had sampled urban trees, as (1) they indicate the amount of heavy metals which could bio-accumulate in the living organisms, (2) the tree-rings reflect the temporal changes of (air) pollutants, and (3) the tree-rings could be repeatedly sampled without hurting the tree itself.

Heavy metals could get in into the tree-rings through the leaves, the root-system or the bark, but the ratio between these uptakes is different depending on the species or local factors (Lepp, 1975). However, the most important route of heavy metal uptake is through leaves (Lin et al., 1995), but it is not proven in case of all urban species (Watmough, 1999). Despite of the uncertainties, the tree-rings are declared to be good archives of atmospheric fallout of heavy metals, thus the pollution history (Brabander et al., 1999; Watmough, 1999; Padilla and Anderson, 2002), or the spatio-temporal variations in traffic could be reconstructed based on a dendrological study (Kadell and Larsson, 1978).

Specific aims of the research were to found an urban bio-monitoring system at Szeged, to monitor the spatial and temporal changes in heavy metal load, and to evaluate the environmental status of the city. The monitoring system was founded at Szeged in 2000 involving 75 urban trees, which represent the entire area of the city, and the same specimens were sampled three times, thus the pollution history of a relatively long period (1996-2017) could be reconstructed.

STUDY AREA

The city of Szeged is located on the Hungarian Great Plain, close to the Romanian and Serbian border (Fig. 1). Therefore, the international transit traffic through the town was considerable, thus the air- and dust pollution originating from traffic have reached the health limits at certain times (Pasinszki, 1996). However, the traffic situation had changed in 2011, when a ring-road highway (M43) was built, thus the roads became less busy within the town. Another factor, which could have influenced the environmental load is the usage of lead-free petrol, which became obligatory in Hungary in 1999. The industrial activity in the town is limited, only some chemical, food and textile companies operate, however it is surrounded by agricultural fields.

The city is dissected by the Tisza River, which influences the ground-water conditions. It could affect the heavy metal accumulation of the trees too, as north of the town the Maros River joins to the Tisza. This tributary transports large amount of pollutants (mainly copper and zinc; Kiss and Sipos, 2001) originating from the geological background of the catchment and from mining activity (Wajjandt and Bancsi, 1989).

METHODS

Sample collection

Tree-ring samples were collected from the entire area of the city with almost equal spatial distribution in 2000, 2005 and 2017 (Fig. 1). During the planning of the bio-monitoring system such tree species had to be selected, which (1) are abundant in the whole city; (2) accumulate heavy metals in the same manner and rate; and (3) were affected by similar environmental effects (e.g. situated along roads). These criteria were fulfilled by *Tilia platyphyllos* and *Populus*

nigra ssp. italica. If the individuals of the two species appeared next to each other, we sampled both of them, to compare the differences in their heavy metal bio-accumulation.

During the first field campaign 73 trees were sampled. Later some of the trees were cut, therefore in 2005 only 67 of them existed, and in 2017 only 57 remained. At each sampling campaign the same individuals were sampled to decrease the errors originating from the different (1) metabolism of individuals; (2) location; and (3) exposure. To evaluate the spatial changes of heavy metal pollution along roads, two main roads with heavy traffic were sampled (Bajai road and Kossuth road). To evaluate the effective distance from a main busy street the trees along a quiet street (Eszperantó str.) joining to a main road were also sampled.

The trees were sampled by increment borer (Lintab, Denmark) at 1.0 m height above ground (Figs. 2-3), at the side of the trunk facing towards the road. During each sampling campaign the outer 5 tree-rings (located in the soft wood) were separated, representing the periods of 1996-2000, 2001-2005, and 2013-2017. Samples were dried (moisture content <5%), and their weight (ranging between 0.5-2.0 g) was measured, so later we could evaluate the biomass production of the trees.

Analytical measurements

The samples represent a 5-year period, thus the heavy metal (Pb, Cd, Cu and Zn) content (ppm) is a mean value for the period. The sample preparations during each campaign were made in the same way. The tree-ring samples were treated in nitric acid (65%) for 24 hours, later they were boiled for 3 hours on 120°C, finally they were treated by HClO₄ (70%). Though the sample preparation was the same, the analytical devices changed during the study. The first two measurements were made using Perkin Elmer 3110

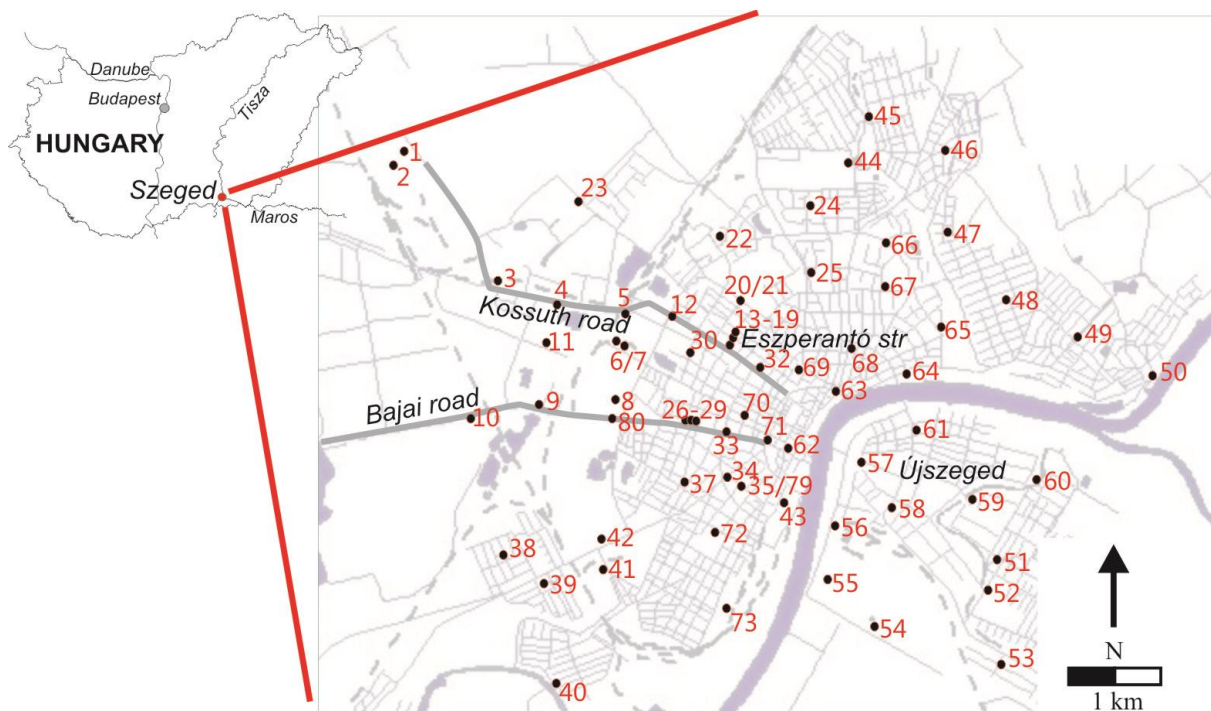


Fig. 1 Location of Szeged (Hungary) and the sampled urban trees

atomabsorptic and emission spectrometer, whilst the last measurement was made by Perkin Elmer 7000DV ICP-OES spectrometer. Based on simultaneous tests, there is no considerable difference between the results of the two devices, though the second one has much better resolution.



Fig. 2 The trees were sampled by increment borer



Fig. 3 Location of former cores and the latest coring at the same poplar tree

Spatial analysis of the results

Based on the range of heavy metal content of the tree rings, the samples were divided into five even classes. The members of class No. 1. contain the lowest amount of certain heavy metal, while trees belong to the class No. 5 accumulated the greatest amount of a given heavy metal. To evaluate the total heavy metal load of a tree and to evaluate the environmental status of the area, the indices of the classes were summarized, and reclassified. In this way the total environmental load of an urban tree at a given location and at a given time could be evaluated (very good / good / medium / satisfactory / bad).

RESULTS

Biomass changes of the tree-rings

The weight or width of tree-rings refers the biomass production of a tree, which reflects its living conditions and the rate of environmental load of the area. In the first period (1996/2000) the mean weight of the 5 tree rings was 0.29 g (Fig. 4), and it reduced to 0.22 g in the next period (2001/05). This considerable decrease (-28%) undoubtedly refer to the declining living conditions of the sampled urban trees. In the last period (2013/17) the mean value did not decrease further on, and some trees even could increase their biomass. These trees are usually along quiet roads where the water supply is more favourable (e.g. less paved surfaces).

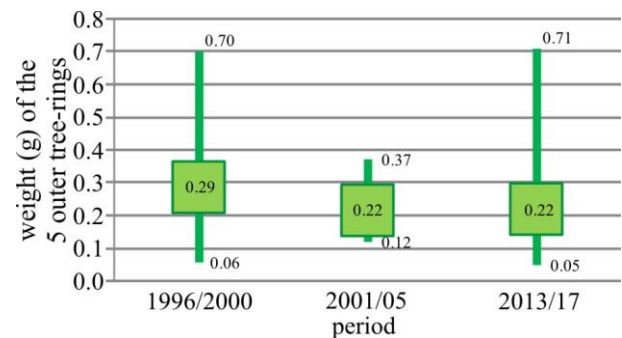


Fig. 4 Weight changes of the sampled 5 tree-rings (representing the maximum, mean and minimum values)

Temporal changes in heavy metal pollution of tree-rings

The amount of accumulated heavy metals considerably changed during the studied period (Table 1). Between the first and second survey the mean lead (Pb) and zinc (Zn) content increased by 2-3 times, whilst of the cadmium (Cd) and copper (Cu) by one order. At the same time the minimum and maximum vales became more similar, reflecting, that whilst in the first period some sites were polluted and others could be considered as unpolluted, in the second period the entire city was more evenly and higher polluted. However, by the third survey (2013/17) the situation improved. The lead pollution decreased by 97% compared to the previous period. The amount of cadmium has also declined by 96%. Similar decrease was detected in case of copper (-88%). However, the amount of zinc gradually increased: until the early 2000s its amount tripled (+288%), and until nowadays it increased by further 51%.

The heavy metal content of the tree-rings increased at almost every sampling point in the second period (2001/05), however in the third period (2013/15) it decreased. To visualise these changes, the heavy metal content of tree-rings in a period was plotted against the next period (Fig. 5 a, b).

Table 1 Temporal changes in heavy metal content (ppm) of the tree-rings

	lead (Pb)			cadmium (Cd)			copper (Cu)			zinc (Zn)		
	1996-2000	2001-2005	2013-2017	1996-2000	2001-2005	2013-2017	1996-2000	2001-2005	2013-2017	1996-2000	2001-2005	2013-2017
min	0.0	6.2	0.0	0.0	2.8	0.0	0.0	0.6	1.2	0.0	0.5	4.2
mean	6.4	11.0	0.3	0.3	5.0	0.2	2.3	27.0	3.4	4.4	12.7	19.3
max	47.7	21.0	1.0	3.6	9.1	1.0	48.9	338.2	20.2	55.1	37.2	82.2

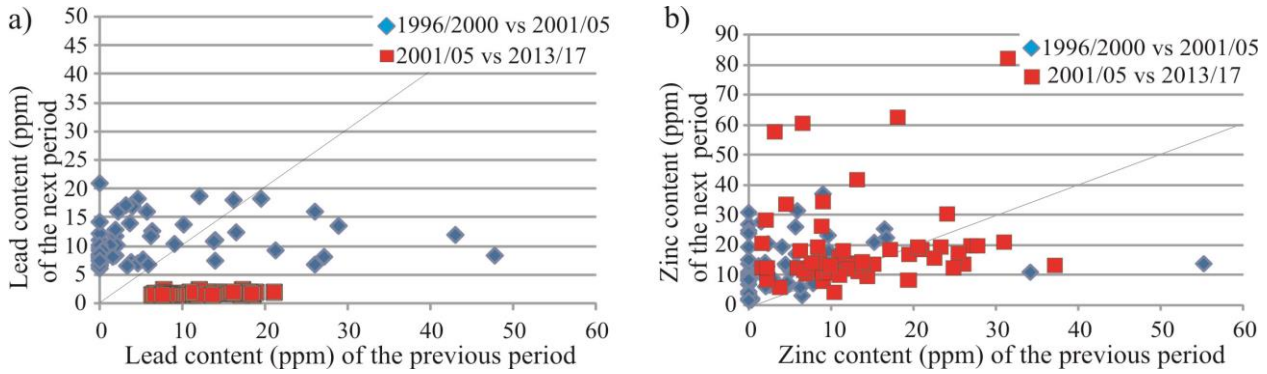


Fig. 5 Comparison of a) lead and b) zinc content (ppm) of the tree-rings measured at the different periods. If a point falls below the line, the concentration decreased by time, but if it is above, the concentration increased compared to the previous period.

In case the rate of bio-accumulation of the have metal remains the same, the point representing a tree should fit to the $x = y$ equation (line). Comparing the results of the first and second period reflects that almost all points fall above the line in case of all studied heavy metals, referring to increased bio-accumulation of these elements in the tree-rings. In contrary, the comparison of the second and third period reflects that the points usually fall below the line in case of lead, cadmium and copper, thus their uptake and accumulation in the trees decreased. The exception is the zinc, as in 60% of the sampled trees its concentration had increased even in the third period.

Spatial distribution of the studied heavy metals

Spatial distribution of lead pollution

The usage of lead-free petrol became obligatory in Hungary after 1999, thus the studied timeframe represent a period (1) when considerable amount of Pb was emitted to the

environment by traffic (1996/2000), (2) consequently after the banning of leaded petrol (2001/05), and finally (3) when (2013/17) the recovery of the environment was more advanced and no lead of traffic origin could get in the air. As most of the lead pollution is considered to have traffic origin, we evaluated it from three different points: (1) spatial distribution in the entire city; (2) along the main traffic routes; and (3) by the distance from a busy road.

In the first period (1996/2000) the lead pollution of the city was low in general, as at 64% of the sampling sites its concentration was below 5 ppm (Fig. 6). However, in 2001/05 it increased, at in all cases it was above 5 ppm. The most polluted areas were along the busy roads, despite of the fact, that at this time the usage of lead-free petrol was already obligatory in Hungary. By the third period (2013/17) the lead content of all sampled trees reduced below 5 ppm, reflecting better environmental conditions in the entire city.

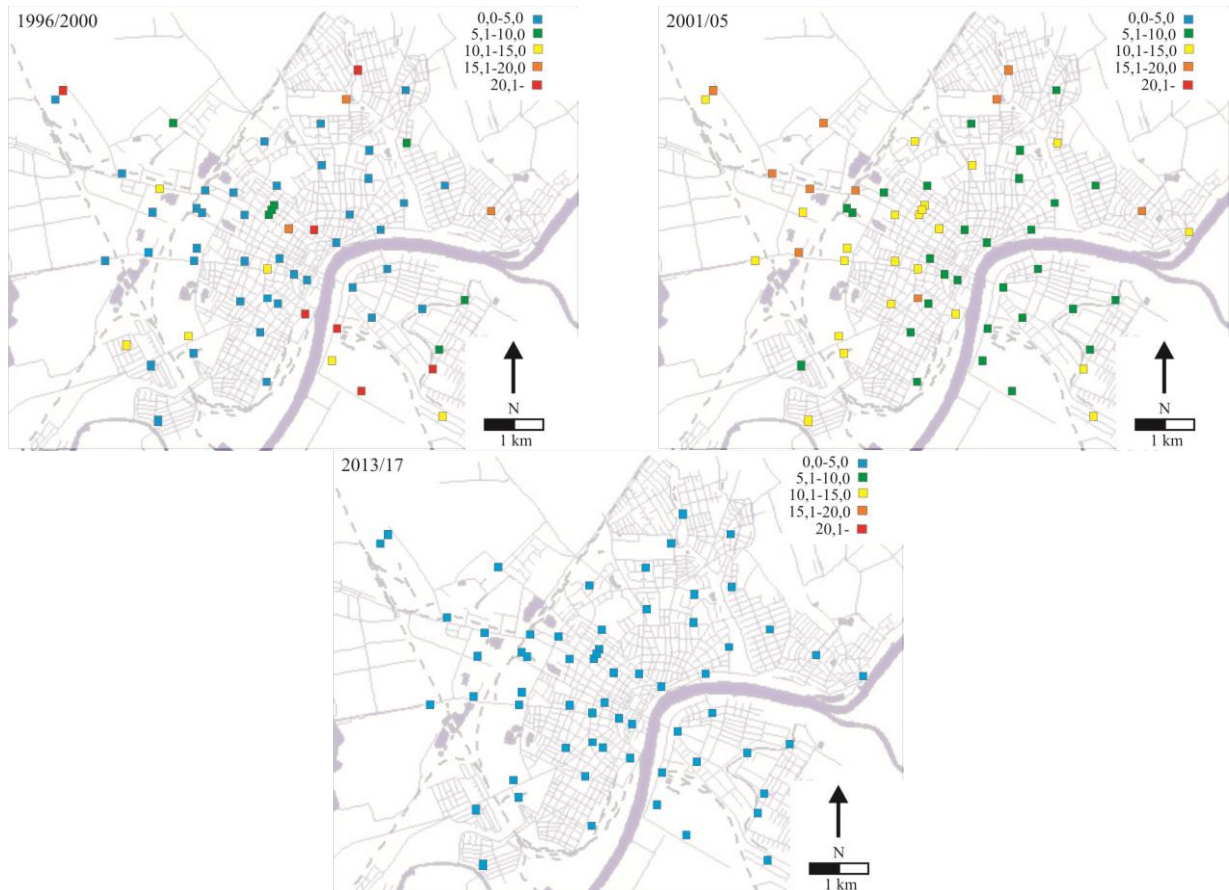


Fig. 6 Spatial distribution of lead content (ppm) in tree-rings at Szeged in the periods of 1996/2000, 2001/05 and 2013/2017

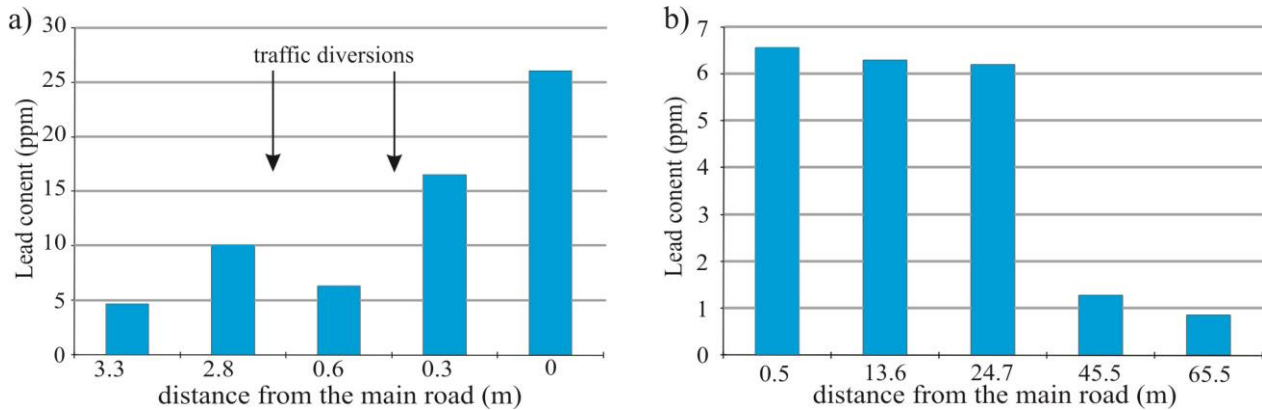


Fig. 7 Lead pollution along the busy Kossuth road towards the city centre in the first period (1996/2000; b) Lead content of the tree-rings in the quiet Eszperantó street, perpendicular to the busy Kossuth road in 1996/2000

Along the studied busy roads, the lead content of the tree-rings was high during the first two periods, almost twice as much than in those in the quiet streets and parks. However, during the last period the differences were not so high, though the along the busy roads the trees had higher lead accumulation. Along the Bajai road the lead content increased towards the city centre (Fig. 7a), parallel to the increasing amount of built-in areas and the lack of ventilation. However, the trees along the Kossuth road refer to another trend. In this case the lead content increases towards the city centre, however it is broken at the circular roads which divert considerable amount of the traffic.

The efficiency of lead pollution dispersal from the main, busy road was studied along relatively quiet street (Eszperantó str) perpendicular to a busy road (Kossuth road). In the first period (1996/2000) the sampled trees within 25 m distance from the main road accumulated almost the same amount of lead (Fig. 7b), only at 30–40 m far from the main road the accumulation started to decrease. The pattern of the pollution was similar in 2001/05, though the trees accumulated much more lead.

Spatial distribution of cadmium pollution

In 1996/2000 cadmium content above the detection limit (2.0 ppm) was measured in 31% of the trees, mainly along the busy roads. Its amount increased in 2001/05, as even in the small parks and quiet streets its amount was above 2.0 ppm. In the first period cadmium appeared just at the busy cross-roads of the city centre, but in 2001/05 it was detectable everywhere, especially along the main roads (Fig. 8), similarly to the spatial distribution of the lead (Fig. 5). In the third period (2013/17), the lead content decreased in every sampled tree to 0.01–1.3 ppm, though it still appeared everywhere. The cadmium pollution of the city – similarly to the lead pollution – was characteristic in the entire territory of the city, though lately less accumulated in the living organisms.

The spatial distributions of lead and cadmium reflect that both pollutants have the highest values at the same places. It could be explained by their origin, as both are related to traffic. The cadmium is emitted

through the wearing of tires and burning of diesel fuel (Csathó, 1994). In the first period (1996/2000) cadmium pollution did not get into the quiet streets, thus no cadmium accumulated in the trees of the side street (Eszperantó str.). However, in the next period (2001/05) it was already detectable, and its amount only slightly decreased (from 6.00 ppm to 4.15 pp) with the decreasing distance from the main road.

Spatial distribution of copper pollution

In the first period (1996/2000), the copper content of the tree-rings was below 5.0 ppm in 97% of the samples. The highest values (18.6 ppm and 48.9 ppm) were measured in the NW part of the city, in an industrial area, therefore, we assumed, that it had in industrial origin. Though in this area the pollution decreased in 2001/05, but all over the city the copper content of the tree-rings has increased, and the most polluted areas shifted from the industrial area towards SE and to the city centre (Fig.9). Only 14% of the trees accumulated less than 5.0 ppm of copper, and extremely high values (100–338 ppm) appeared in 5 trees, four of them located in the city centre. At the same time, newer polluted areas appeared in the N and SW parts of the city, where the trees accumulated 20–40 times more Cu than before. In the last period (2013/17) the copper pollution dropped, as in most of the trees the copper content decreased below 5.0 ppm. Only one tree, in the NW industrial area accumulated 20 ppm copper

Spatial distribution of zinc pollution

Among the studied pollutants only the amount of zinc has increased throughout the three studied periods, thus the zinc pollution is getting worse in Szeged (Fig. 10). In the first period (1996/2000) 86% of the trees accumulated less than 10 ppm of Zn, and only two trees had high zinc content (55 ppm and 34 ppm). In the next period (2000/2005) only 40% of the trees accumulated less than 10 ppm. In the latest period (2013/17) the Zn content of the tree-rings increased further on, only 12% of the trees had less than 10 ppm Zn. These trees are located in the city centre and in the suburb of Újszeged. Especially high amount of zinc (57–82 ppm) was found in the trees located in NW part of the city.



Fig. 8 Spatial distribution of Cd content (ppm) in tree-rings at Szeged in the periods of 1996/2000, 2001/05 and 2013/2017.

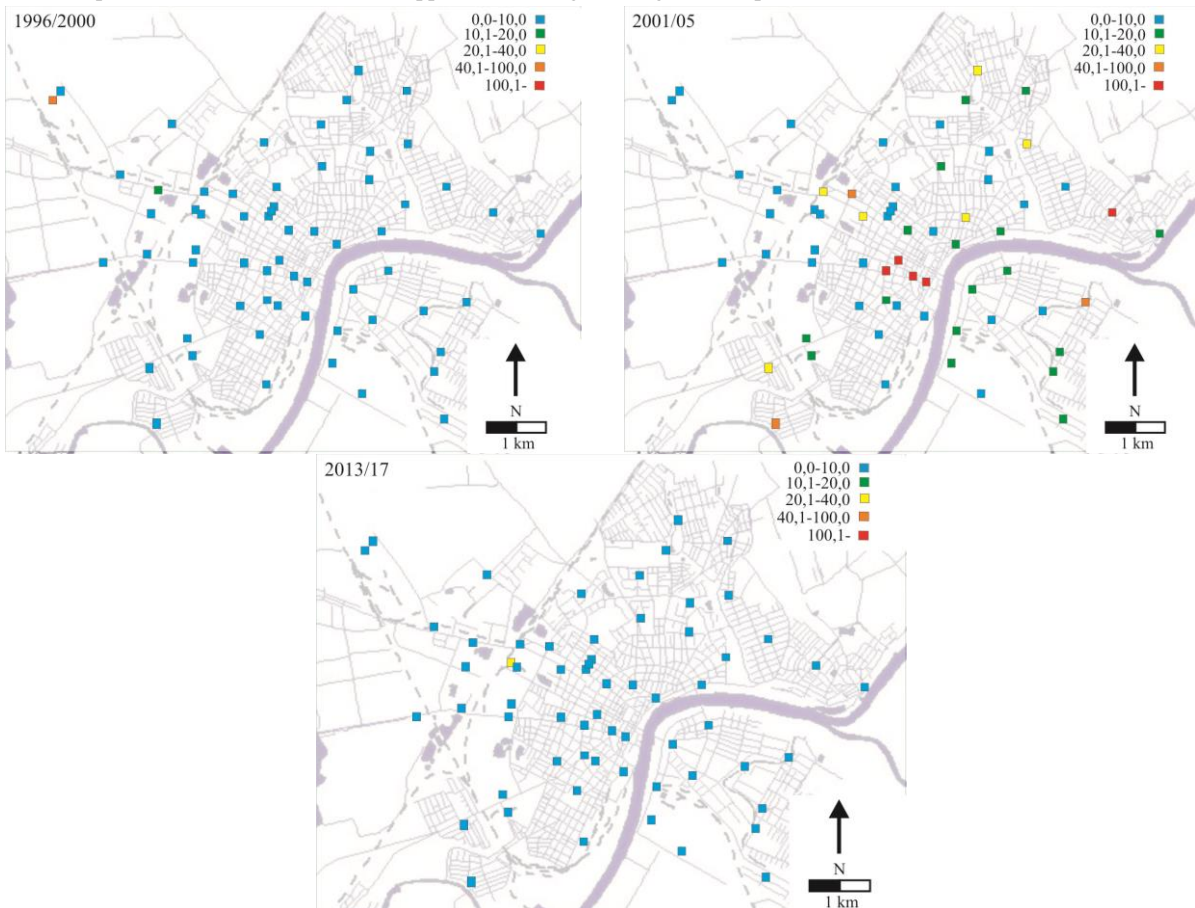


Fig. 9 Spatial distribution of Cu content (ppm) in tree-rings at Szeged in the periods of 1996/2000, 2001/05 and 2013/2017

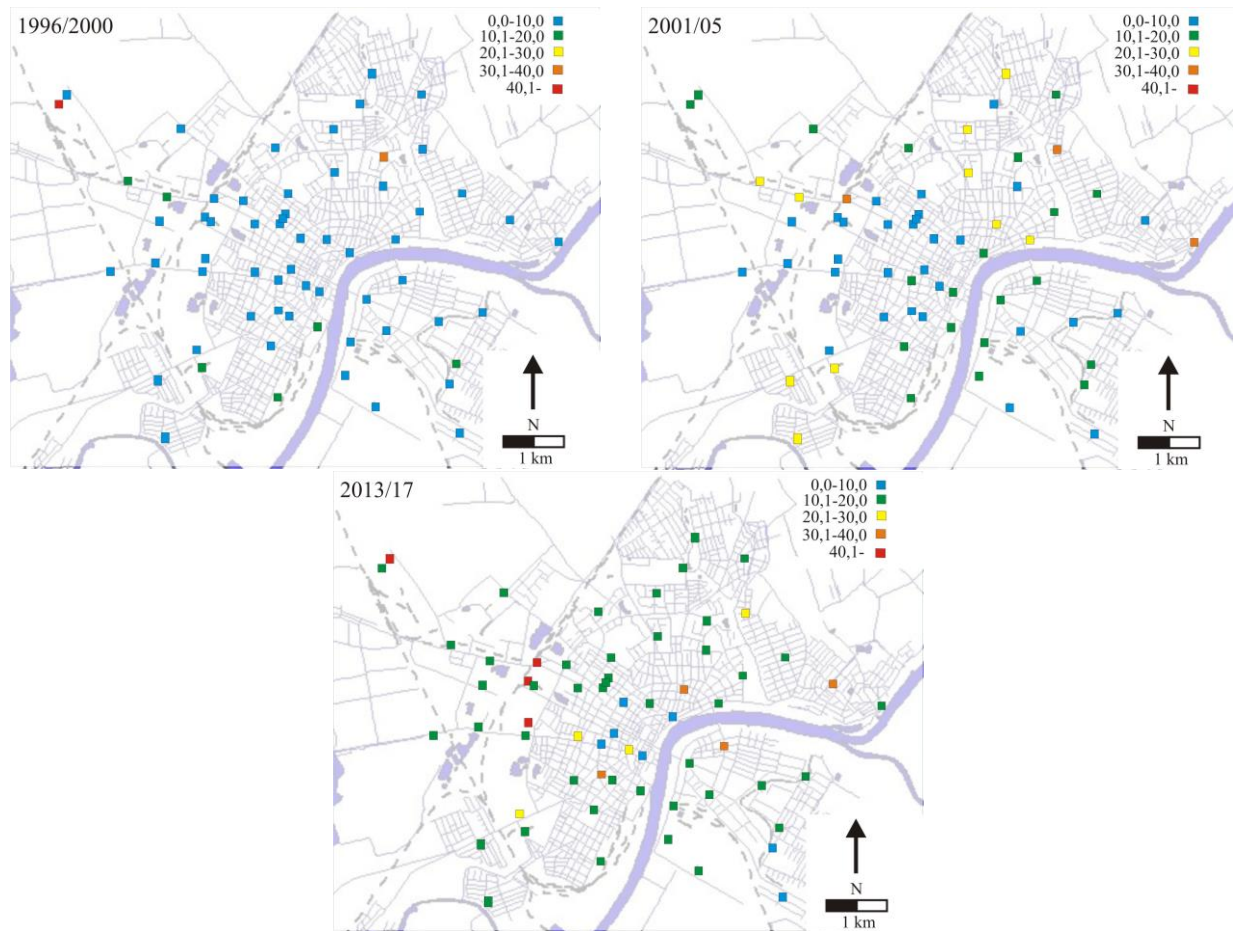


Fig. 10 Spatial distribution of Zn content (ppm) in tree-rings at Szeged in the periods of 1996/2000, 2001/05 and 2013/2017

DISCUSSION

Spatial and temporal changes in heavy metal bio-accumulation

In general, the living conditions of the urban trees (and other organisms as well) at Szeged was the worst in 2001/05, when the heavy metal pollution was the greatest, therefore the biomass production of the sampled trees decreased (-28%). It is parallel to the results of Fischer et al. (2002), who found negative correlation between tree-ring width and its lead content. However, the living conditions of the trees in Szeged did not become more favourable ever since, nor it became worse, as the biomass of the tree-rings remained the same. This reflects that despite of the decline in heavy metal pollution some other stress factors became stronger, creating unfavourable urban environment for the trees. Probably the low wood-biomass is connected to the hotter and drier summers (Ladányi and Blanka-Végi, 2015), as Szeged is the hottest city in Hungary.

The temporal change in lead pollution (considerable decline in 2013/17) could be explained by the obligatory usage of lead-free petrol. In Hungary it is used since 1999, but no data exists for the neighbouring countries (Romania and Serbia), though the international traffic through the city was high until 2011, when a circular highway was built to divert the through-traffic from the town., though some years had to be passed to eliminate

from the air. Thus, the first period (1996/2000) was characterised by intensive lead emission, and during the second period (2001/05) its amount was supposed to decrease. However, the comparison of the periods suggests, that the introduction of unleaded petrol had delayed favourable results, as by 2001/05 the lead content of the tree-rings increased by 3-4 times, and it decreased just later, in the third period. This could be explained by the fact, that lead is connected to small dust particles (Pasinszki, 1996), these particles just gradually became fixed in the soil or they were washed out from the town during heavy rains, thus these particles probably circulated in the air for a while. The extended presence of the lead in the air was also proven in 2005 (Csemete Association, unpublished report, 2006). This temporal lag of lead output from the city suggests, that the lead (and also other heavy metals) could be-mobilised repeatedly in the city, thus it was repetitively available for foliage uptake for the trees much longer, then it was expected. The cadmium pollution also declined in 2013/17, after the international traffic was diverted from the city. The cadmium pollution is connected to the usage of brake-linings (Grigoratos and Martini, 2015), thus as the transit-traffic decreased after the construction of the M43 highway in 2011, much less cadmium could get in the air.

Along the studied busy roads, the bio-accumulation of lead in tree-rings was twice as much as along less busy roads during the first and second period, fitting to former European studies (Watmough, 1999). In the third period the differences in lead content was smaller, however its

spatial trend was the same. Along the quite busy Bajai road and Kossuth road the lead concentration gradually increased towards the city centre, though at Kossuth road it decreased at a large junction (Fig. 8.). This phenomenon reveals, that the outer ring-roads, which divert the traffic, play important role in decreasing the environmental load of a city. This phenomenon points on the importance of road diversions, which could be applied to decrease the environmental load of the heavily built-in areas, as in these cases the narrow and badly ventilated streets enclosed by high houses trap the dust particles containing lead. This idea is supported by the measurement of Pasinszki (1996), who found positive linear correlation between the rate of deposited dust and the lead pollution of the air.

In our case the pollutants were dispersed further from the busy road, then it was reported in the literature, as according to Kardell and Larsson (1978) the busy roads effect the pollution of the side roads just within 20–25 m buffer zone, while at Szeged the effective distance is ca. 30–40 m.

Whilst the lead and cadmium content of the tree-rings decreased during the studied decades, the trees accumulated increasing amount of zinc throughout the studied periods. Nor the zinc, neither the copper content of the tree-rings reflects any spatial tendency along the main roads, thus they are not related to traffic. According to the data their concentrations are proportional to the age of the tree, the size of the canopy and root system. Thus these elements either could be deposited from the air and in this way they got onto the leaves and into the tissues, or could be up-taken from the ground-water, as the larger the canopy of a tree the denser and deeper its root system is. Unfortunately, no data exists on the air pollution of the city, but presumably the copper pollution originated from an agricultural activity, as copper is often used in pesticides. The greatest zinc pollution characterised the trees growing at the outskirts, along the Tisza River and an ox-bow-lake of the Maros River. Thus, probably the zinc was transported to the town by wind or by ground water. The root-uptake could be verified by the fact, that the water and the sediment of the Maros River contains large amount of zinc (Waijandt and Bancsi, 1989; Kiss and Sipos, 2001), and also the ground water has high zinc content (Fejes 2014).

Relationship between the type of built-in areas and heavy metal content

The spatial distribution of the studied heavy metals was compared to the built-in types of the city, referring to the environmental load of a given area, thus to the life conditions of the citizens. Some heavy metals were deposited from the air and were built into the tree-rings through leaf-uptake, probably similar rate of heavy metals could get into the human body through inhalation. It is especially valid for the lead and cadmium pollution, which are both closely related to the traffic and its dust production.

The mean heavy metal pollution of the *densely built-in city center* was relatively low in 1995/2000 and 2013/17 (Fig. 11). It could be probably explained by the shading effect of the tall, densely built detached houses, thus the pollution could not spread far from the

sources. However, in the period of 2001/05 this area became polluted. Until 2005 the lead-born environmental risk of this area was closely related to traffic and to the usage of leaded petrol, but only those areas and living organisms were closely affected, which located in 50–60 m distance from the main roads, or at local or regional bus stations.

The environmental status of the *northern living areas with block-of-flats* is relatively good, except along the busy roads, where the data of the first two measurement periods refer to medium of moderately bad pollution. However, the environmental status of these areas also improved.

Some parts of the *suburban* areas are the most polluted. Toward the industrial area and the city centre (Rókus, Alsóváros suburbs) the environmental load increased until 2001/05, but since that time these areas became less polluted. In general, the south-eastern part of the town (Újszeged) is the less polluted. Relatively large concentrations were built only along the roads or at some points, where previous waste disposals or traffic junctions were located.

The northern *industrial area* is the most polluted, though the other small industrial centres are also characterised by high values. These are such a places of the town, where though the absolute heavy metal concentrations in tree-rings is decreasing, but these concentrations compared to the other parts of the city are still high. In these neighbourhoods housing is rare, thus these areas are responsible for relatively low environmental risk for humans.

It could be stated, that the tissues of urban trees, as living organisms, reflect considerable changes in spatial and temporal dispersal of pollutants. In the first period (1995/2000) the city of Szeged was characterised by low heavy-metal load, but during the next period (2001/2005) the situation considerably became worse, as heavy metals appeared in all studied trees all over the city, and even worse than that, their amount was multiplied. Fortunately, the environmental conditions became better, only there are some points in the industrial area, where the heavy metal pollution of the environment is gradually increases.

CONCLUSIONS

According to former researches (Lepp, 1975, Kardell and Larsson, 1978; Temminghoff et al., 1998) the copper, cadmium and lead uptake of trees is the greatest through the foliage. Some metals could be relatively mobile in the soil, however, only at low pH values (Csathó, 1994), but the soils in Szeged city are slightly basic or basic (Fejes, 2014). Therefore, at Szeged the heavy metals above probably originated from air pollution, and they got into the tree-rings through foliage uptake. This is also supported by the spatial distribution of pollutants within the city, and their temporal changes.

The heavy metal content of tree-rings considerably increased in the second period, in 2001/05, compared to the previous and subsequent periods. While in the first period only some sampling points were considered as polluted, in 2001/05 the urban environment of Szeged was affected by higher and more uniform heavy metal



Fig. 11 Changes in environmental status of the sapling points based on the summarised heavy metal load of the tree-rings

pollution. The deteriorating life conditions are also shown by the declining biomass. Though the environmental hazard due to heavy metal pollution seems to be reduced, other factors (e.g. drought, heat-stress) increase the exposure of urban trees to environmental stress, thus the tree-ring width and biomass production remained low.

The spatiality of heavy metal concentrations in tree-rings refers to the variations in environmental load of the various parts of the city. The greatest amount of pollutants was measured in trees along the busy main roads and in the north-western part of the city. Some parts of the heavy metal pollution (lead and cadmium) is undoubtedly originates from traffic, while other parts (copper and zinc) originates from other (yet unknown sources) and the trees can accumulate them through the root-system (from groundwater) or the leaves (from air). As the lead and cadmium pollution mainly appear along within 30–40 m buffer zone of main roads and busy junctions, the environmental status of these areas improved since the usage of unleaded petrol and the diversion of international through traffic. The spatial pattern of some heavy metals (copper and zinc) is changing by time, and in case of zinc more and more sampling sites are polluted, and the degree of pollution also increases.

This researched proved, that a long-term bio-monitoring study is a useful tool to analyse the spatial and

temporal changes of the environmental risk, which does not only determine the living conditions of urban trees, but also influences the quality of the human environment.

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RECENT DUNE MIGRATION ALONG THE COASTAL PLAIN OF CANOA QUEBRADA,
CEARÁ STATE, NORTHEAST BRAZIL

**Adriana Albuquerque Pedrosa¹, Vanda Claudino-Sales^{2*}, Iltabaraci Nazareno Cavalcante³,
Alexandre Medeiros Carvalho⁴**

¹Secretary of Education of the State of Ceará, Avenida General Afonso Albuquerque Lima, 60822-325 Fortaleza, Ceará, Brazil

²Department of Geography of the Federal University of Ceará (UFC), and Master of Geography of the State University of Acaraú Valley (UVA), Bloco 911, Campus do Pici, 60.440-544 Fortaleza, Ceará, Brazil

³Department of Geology, Federal University of Ceará, Bloco 912, Campus do Pici, 60.440-544 Fortaleza, Ceará, Brazil

⁴Marine Sciences Institute (LABOMAR), Federal University of Ceará, Avenida da Abolição 3207, 60.165-081 Fortaleza, Ceará, Brazil

*Corresponding author, e-mail: vcs@ufc.br

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Abstract

In the coastal area of Ceará State, northeast Brazil, there are large mobile dunefields, including barchans, barchanoid dunes and sandsheets. The migration rate of these dunes, as measured by several studies, varies between 32 m/y and 9 m/y. This paper analyzes the migration of the dunes in Canoa Quebrada Beach, located in the eastern coast of Ceará State, using remote sensing of aerial photos and satellite imagery from 1988 to 2013 (25 years). The resulting data indicate an average migration rate varying from 1.8 m/y to 9.3 m/y. This is the lowest rate of migration measured for large and undeveloped mobile dunes in Ceará State. The analysis indicates that the element responsible for this low rate is the low wind speed. However, the installation of wind power turbines in the area – which demanded the fixation of part of the dunes to prevent the equipment from being buried and from aeolian erosion – might be another reason for the decreasing dune migration. The dune migration decrease may increase the sedimentary deficit in the coastline downdrift of Canoa Quebrada Beach.

Keywords: dune migration, coastal dynamics, Northeastern Brazil, coastal development

INTRODUCTION

Mobile aeolian dunes are accumulations of medium to fine sands characterized by the absence of vegetation cover or cementation. They occur in coastal plains, continental desert areas, and in the vicinity of fluvial and lacustrine beaches and plains. The mobile aeolian dunes migrate when they are mobilized by winds and, therefore, are constantly changing form and position while the wind reorganizes their sand disposition.

In general, it is considered that the intensity of dune migration depends on the variations of the intensity and direction of annual, seasonal and daily winds, as well as of the turbulence patterns of winds (e.g. Tsoar et al., 1999), of the granulometry of the sediments (e.g. Kocurek and Lancaster, 1999; Livingstone et al., 2007; Potter and Weigand, 2016), of the topography of the surface (e.g. Bristow et al., 2000; Necsoiu et al., 2009), of the intensity of atmospheric precipitation (e.g. Hunter et al., 1983; Maia et al., 2005; Forman et al., 2009), of the moisture content of the sands (e.g. Sherman and Bauer, 1993; Tsoar and Arens, 2003; Potter and Weigand, 2016) and of the wind direction related to the shoreline orientation (Carvalho et al., 2016). It is considered that wind velocities of the order of 3 m/s are able to mobilize medium sands (Paula et al., 2016), and that if conditions are suitable – e.g. dry, open sand surface – the wind can transport even the coarse fraction of the sand (Györgyövícs et al., 2014).

Small dunes migrate faster than larger ones (e.g. Jimenez et al., 1999; Carvalho et al., 2006), and displacements of 1 m/year can take place during the action of strong winds (e.g. Cooke et al., 1993). In the Sahara Desert, measurements indicate a migration rate of the order of 50 m/y for barchan dunes (Vermeesch and Leprince, 2012). In Antarctica, a study identified a rate of dune migration of 0.5 to 1.3 m/y (Bristow et al., 2010). A study about rates of dune migration of active subarctic dunefields indicates an annual migration varying from 0.5 m to 1.5 m (Necsoiu et al., 2009). In Great Britain, a research about the rate of migration of transgressive dunes gave an annual average of 1 m (Bailey and Bristow, 2004). In the Great Lakes area of United States, a study of the migration of continental dunes in a lake shoreline attained a maximum rate of 3.3 m/y (Kilibarda and Shillinglaw, 2014). At the Taklamakan Desert, China, measurements resulted in rates of dune migration of the order of 7.2 to 5.5 m/y (Zhibao et al., 2000). Dune migration in an estuary in New Zealand was identified at a rate of 5 m/y (Shepperd, 1987).

In the coastal area of Ceará State, in the northeast of Brazil (Fig. 1), large mobile dunefields formed by barchans, barchanoid dunes and sandsheets occur along its 573 km of length. The velocity of dune migration is high and has already been measured in some segments of its west coast. The resulting values appointed to a migration of the order of 17 m/y in Jericoacoara (Jimenez et al., 1999), of the maximum order of 12.5 m/y in

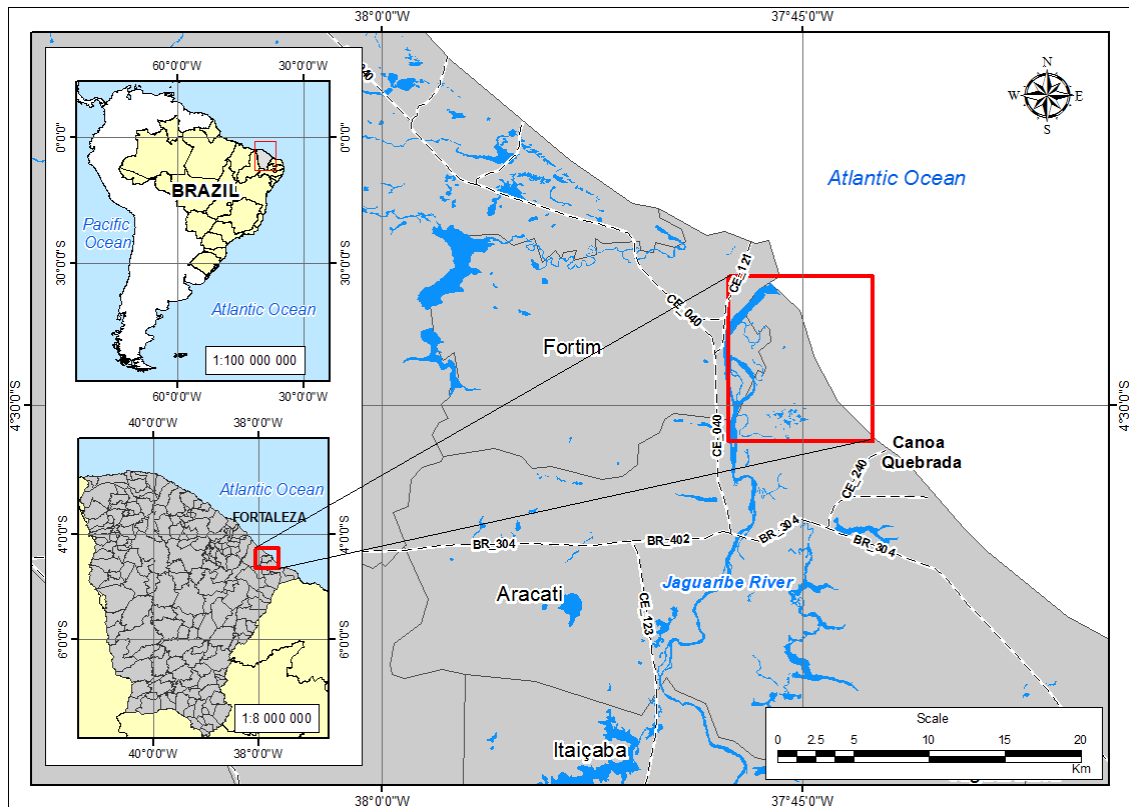


Fig 1 Location of the study area, the Canoa Quebrada Coastal plain, situated at the east segment of Ceará State coast

Paracuru (Castro, 2005), of 32 m/y for small barchans and of the order of 23 m/y for large barchanoid in the same area (Carvalho et al., 2006), and from 14 m/y to 19 m/y in Flecheira/Baleia beaches (Carvalho, 2003). Up to now, no measurements were made for the east coast of the state, a segment that is characterized by the presence of seacliffs extending for around 100 km and by less intensity of wind speed (Maia, 1998). It is important to mention that along this coast, wind-turbines have been installed in the last decade, which might affect the migration of the dunes. Nevertheless, no measurements have been made to evaluate the extent of the change.

In the other states that compose the Brazilian equatorial northeast, the intensity of dune migration defined by several studies present the same patterns of those identified in the coastal area of Ceará State: the rate of migration is in general higher than 10 meters per year. Illustrating this pattern, it is possible to highlight the migration in the coastal area of Piauí State - of the order of 21 m/y; in the state of Maranhão, where it can reach a maximum value of 25 m/y (Santos and Santos, 2015); and, finally, in the state of Rio Grande do Norte, where the dunes migrate with an intensity of at least 23 m/y (Carneiro et al., 2012).

The migration of dunes along the Ceará State coastal area is very important for the sedimentological budget of the area, considering that the region is semi-arid, with small production of fluvial sand. For this reason, an insignificant amount of sand is transported by rivers to the ocean, in order to nourish the beaches downdrift (Maia, 1998). The dunes, in doing the bypass across headlands and fluvial-marine plains, feed rivers with sediments, in such a way to contribute to the equilibrium of the coastal area (Maia,

1998; Claudino-Sales, 2002; Carvalho, 2003; Meireles, 2011; Claudino-Sales et al., 2018). In terms of environmental problems and dune mobilization, it is worth mentioning that in some places, there are conflicts between mobile dunes and urban structures, which have been installed in their path of migration.

In this paper, the migration of the dunes in the coastal area of Canoa Quebrada Beach, located in the east coast of Ceará State, is analyzed. The rate of dune migration at this area, identified here for the first time, has a current behavior completely different from the rate of migration identified for the other segments of the Brazilian northeast coast. The characteristics, as well as the reasons for the particularity of dune migration processes in Canoa Quebrada – such as natural driving forces, as well as those controlled by social activities, e.g. wind-turbine plants and tourism – are analyzed and discussed.

STUDY AREA

The coast of Ceará State, Northeastern Brazil (Fig. 1), consists mostly of long and wide quartz sand beaches, interrupted by small estuaries with mangrove formed by intermittent rivers, as well as by seacliffs, beach-rocks and headlands. The area is characterized by the presence of large transgressive coastal dune complexes distributed up to 6 km landward of the coastline. Small barrier-islands are present, especially in the west coast (Claudino Sales, 2002; Hesp et al., 2009).

Tertiary rocks, represented by the “Barreiras Formation,” is the most important type of deposition in terms of spatial distribution and control of regional coastal sedimentology. The Barreiras Formation displays a

complex lithology ranging from conglomerates, sandstones and mudstones of terrestrial (Bigarella, 1975) and marine (Claudino-Sales, 2002) origins. It creates a low-lying tabular surface with less than 40 m in elevation that extends from the shoreline to 60 km inland. In the vicinity of the shoreline, the tabular surface is covered by aeolian sediments from both active and inactive dunes. In the east segment of the coast, Barreiras Formation outcrops as seacliffs 7 to 15 m high. In addition, it makes several headlands along the coast. (e.g. Claudino Sales and Carvalho, 2014).

Despite its tropical subequatorial location, Ceará state is dominated by an unusual semi-arid climate. The semi-arid characteristics are not directly reflected in the total annual rainfall value, which is relatively high compared to other semi-arid areas in the world (INPE, 2018). The semi-aridity is reflected in its great inter-annual variability, with more than 90% of the rain falling during the 3-month wet season, between mid-March and mid-June.

Temperature remains largely constant throughout the year, with monthly averages ranging between 25.5 °C and 27.5 °C in the coastal area (INPE, 2018). Due to this persistent high temperature and the resulting high potential evaporation, a severe water deficit of more than 1,000 mm occurs in the dry season in the coastal region (SEMACE, 1997). In addition, rivers with even drier catchment area are mostly periodic waterflows, not adding any important amount of sand to the seashore (Maia, 1998).

The climatic conditions of northeastern Brazil are mostly controlled by the Atlantic Ocean circulation system known as the “Intertropical Convergence Zone”- ITCZ (e.g. Wang et al., 2004). ITCZ is related to the sector of the globe where humid atmospheric masses coming from northern and southern hemispheres collide. During the first semester of the year (especially during March and April), the ITCZ is at its southernmost position over Ceará, resulting in the peak rainy season. After April, precipitation starts to decrease as the ITCZ shifts northward, reaching its northernmost position during the second semester of the year (September and October), leading to the peak of the dry season.

Another global scale control on the region’s climate is the El Niño Southern Oscillation (ENSO) cycle. Maia et al. (2005) pointed out that ENSO tends to strengthen the dry season in the Equatorial segment of the northeastern Brazil, while Hastenrath and Heller (2006) suggested that it strengthens the wet season. In such a context, it is evident that, as compared to the ITCZ, the influence of ENSO on the regional climate regime is not yet well understood.

In the Ceará state coastal area, the wind conditions vary considerably from dry season to wet season, controlled by the seasonal migration of the ITCZ. It demonstrates a similar pattern as that of the precipitation variation, but with an opposite trend. Generally, as the precipitation rate decreases, the wind speed increases and reaches a peak speed during the peak dry season. Wind speed may exceed values of 15 m/s, but it goes from 4 m/s in the wet season to 8 m/s on average in the dry season, with annual averages of 5.5 m/s (e.g. Maia, 1998). The wind has a constant easterly direction, controlled by the trade winds. A unique aspect of this stretch of coastal area is that it is never influenced by severe storms.

Driven by the persistent and strong unidirectional winds especially during the dry season, as well as to the dominantly dissipative or intermediate type of meso-tidal beaches (Maia, 1998, Claudino-Sales, 2002; Carvalho and Claudino-Sales, 2016; Pinheiro et al., 2016), dunefields are very well developed along the Ceará coastal area.

The dunes occur as both stable vegetated older dunefields and modern transgressive dunefields (e.g. Claudino-Sales, 2002; Claudino-Sales and Peulvast, 2002). Luminescence dating of sand samples (~1 m below the surface) from vegetated dunes along the coasts of Ceará yielded ages ranging from 135 ky to 100 yr BP (Tsoar et al., 2009). Generally, the dunefields are composed of lunar-shaped/barchans and transverse dune ridges, with fixed parabolic “hairpin” dunes and aeolianites in the seaward segment of the coast (Maia, 1998; Claudino-Sales, 2002; Claudino-Sales and Peulvast, 2002; Carvalho, 2003; Carvalho et al., 2010). Mobile transverse dunes vary in height from less than 15 m to 55 m.

The vegetation in the dunefields is characterized by the presence of species of the halophile-psamophile community (especially *Ipomoea pes-caprae* and *Sporobolus virginicus*) in the mobile segment, and by species of the coastal tropical forest (especially *Anacardium occidentale* and *Byrsonima sericea*) in the vegetated dunefields (Moro et al., 2015).

The wave conditions in the Ceará State coast are also strongly influenced by the persistent and unidirectional trade winds. According to the National Institute of Navigation Research – INPH (1996), the predominant wave direction as measured at Pecém beach is 90°, i.e., approaching from the east. The waves are mainly of the sea type, with occasional occurrence of NE swell originated in the northern Hemisphere from November to March (Maia, 1998). The most frequently occurring wave heights range from 1.0 to 1.5 m, with period of 5 s (Claudino-Sales et al., 2018; Maia, 1998). The Ceará State coastal area is characteristic of a semidiurnal mesotidal regime with a spring tidal range of approximately 3.1 m (DNH, 2018), and an average range of 2.64 m.

Canoa Quebrada Beach, as studied in this paper, is located in the east segment of Ceará State coast (Fig. 1). The studied coastal segment is 11 km long, occupying an area of 2,500 ha. The landscape, as seen in the geomorphological map (Fig. 2), is characterized by the presence of long sandy beaches interrupted at the west by the mouth of the Jaguaribe River – where the fluvial-marine plain is colonized by mangrove. The strand is marked by the presence of active seacliffs shaped in the Barreiras Formation (Fig. 3A), which extend for around 30 km from SE to NW, as well as by littoral bars (see Figure 2). Coastal tablelands are also modelled in the Barreiras Formation in the inner coastal area, and are largely covered by mobile dunefields and interdune ponds (Figs 2 and 3B) (Pedrosa, 2016). The mobile dunefields of Canoa Quebrada are of the barchans type (lower number), barchanoids (abundant) and sandsheets (dominant) (Pedrosa, 2016). There are also semi-fixed dunes in contact with the mangroves (Figs. 2 and 3C). The vegetation of the mangrove is, in this case, the major factor in the fixation of the transgressive dunes that

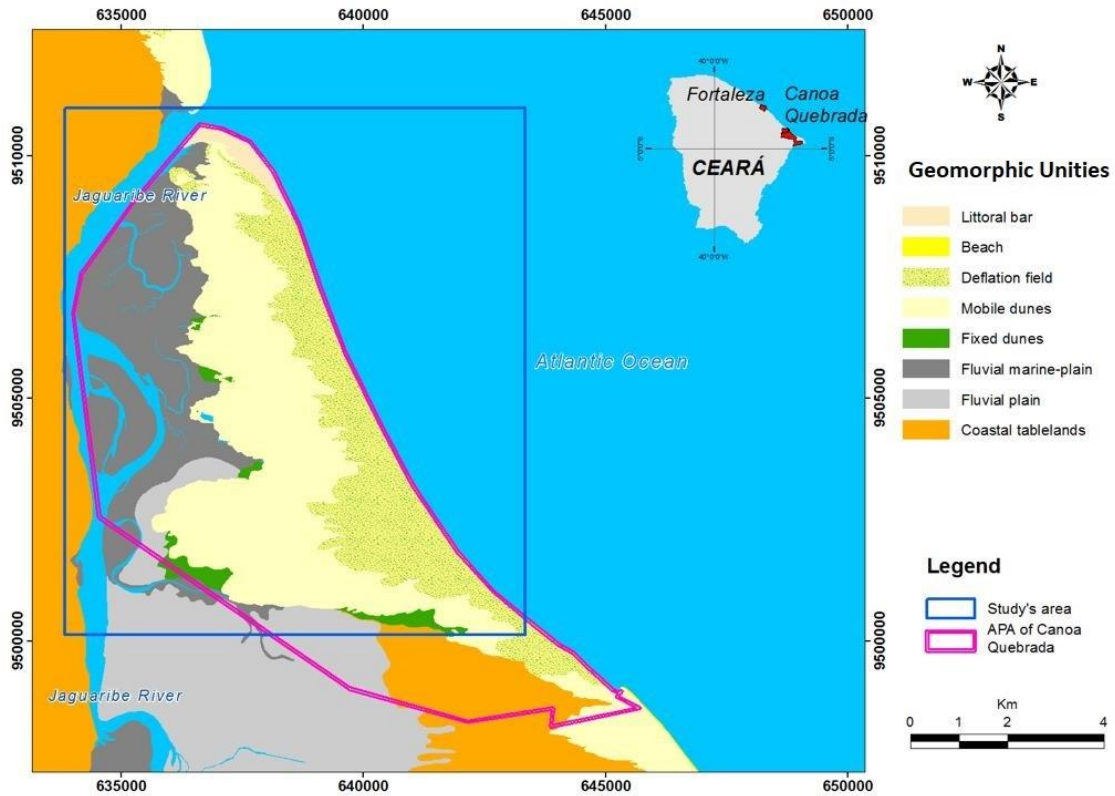


Fig 2 Geomorphology of Canoa Quebrada Beach, with indication of the presence of an Area of Permanent Preservation (APA) in the study area

migrate into the fluvial-marine plain direction. The dunes present maximum heights of 34 m (Fig. 3D) (Pedrosa, 2016). They are formed by medium and fine well-selected sands (Maia et al., 2006).

The pluvial regime in Canoa Quebrada is mild tropical. The annual average precipitation rate reaches 1,024 mm (FUNCEME, 2015). September is the driest month, with only 5 mm of rain. The majority of the

precipitation occurs in March, with a monthly average of 264 mm. The annual average temperature is 27.1°C (FUNCEME, 2015) (Fig.4).

Most of the studied area is part of the “Area of Permanent Preservation – APA” of Canoa Quebrada (for location of the APA, see Figure 2). The APA was defined by state law in 1998, and has the goal to preserve the biotic communities, fixed and mobile dunes, seacliffs, ponds,



Fig. 3 Coastal features in Canoa Quebrada Beach. A. Seacliffs modeled on Tertiary sediments in Canoa Quebrada Beach B. Mobile transgressive dunefields with interdune ponds. C. Transgressive dunes being fixed in contact with mangroves at the fluvial plain of Jaguaribe River. D. Thirty-four meters high barchan dune in Canoa Quebrada Beach coastal area

mangrove, reefs and soil. It also allows the development of the land, in the measure that the uses and occupations intended do not result in degradation of the natural attributes of the environment. The principal economic activity practiced in the APA is geotourism and ecotourism. In the last decade, wind-turbine plants were installed.

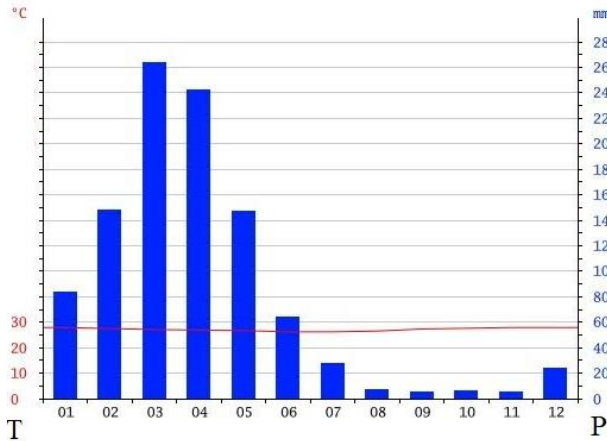


Fig. 4 Graphic of temperature (T) and precipitation (P) in Canoa Quebrada coastal area (meteorological station placed at Aracati, 30 km from the study area) for the year 2015

METHODS

The dune migration rate analysis along the Canoa Quebrada municipality covered the interval of 25 years, related to the period 1988 - 2013. Therefore, aerial photographs, scale 1: 25,000, of the year 1988, as well as satellite images “Quick bird” of the years 2004, 2010 and 2013 were used. Besides Google images, those were the

only images found for the area in the Brazilian public and private sources. The location of the transects used in this research using the photographs and satellite images is indicated in Figure 5.

The determination of the migration rate of the dunes was obtained with the help of the tool “Digital Shoreline Analysis System – DSAS 3.2”, applied to the ArcMapGIs 9 software. The DSAS is an extension that enhances the normal ArcGIS software functionality. It allows the user to calculate change rates of a statistical series, considering the time and the multiple positions of successive lines drawn in the satellite images of the coastline (Oliveira, 2005; Thieler et al., 2005). The tool was used for this study, to allow measuring the lines of advancement of the dunes along the coastal plain.

The DSAS works by generating orthogonal transects at a spacing defined by the user, which in this case was 200 m. It calculates the change of rates between space and time, generating the statistics that are shown in an attribute table. The statistical method tool was the linear regression (LRR).

The DSAS tool was applied from the creation of lines in shapefile format in ArcMapGis 9 software. The boundary line of the dunefields, on the leeward side, was created for each year of observation, enabling the multi-temporal analysis. A baseline was acquired, also in shapelifile format, set perpendicular to the direction of dune migration. The observation of the direction of migration was made using the satellite images, overlapping one and the other.

Finally, the tool that creates the transects was applied, also in shapefile format, for calculation of the migration rates. Each transect passing the lines calculates the rates, considering the space and the existing time between them.

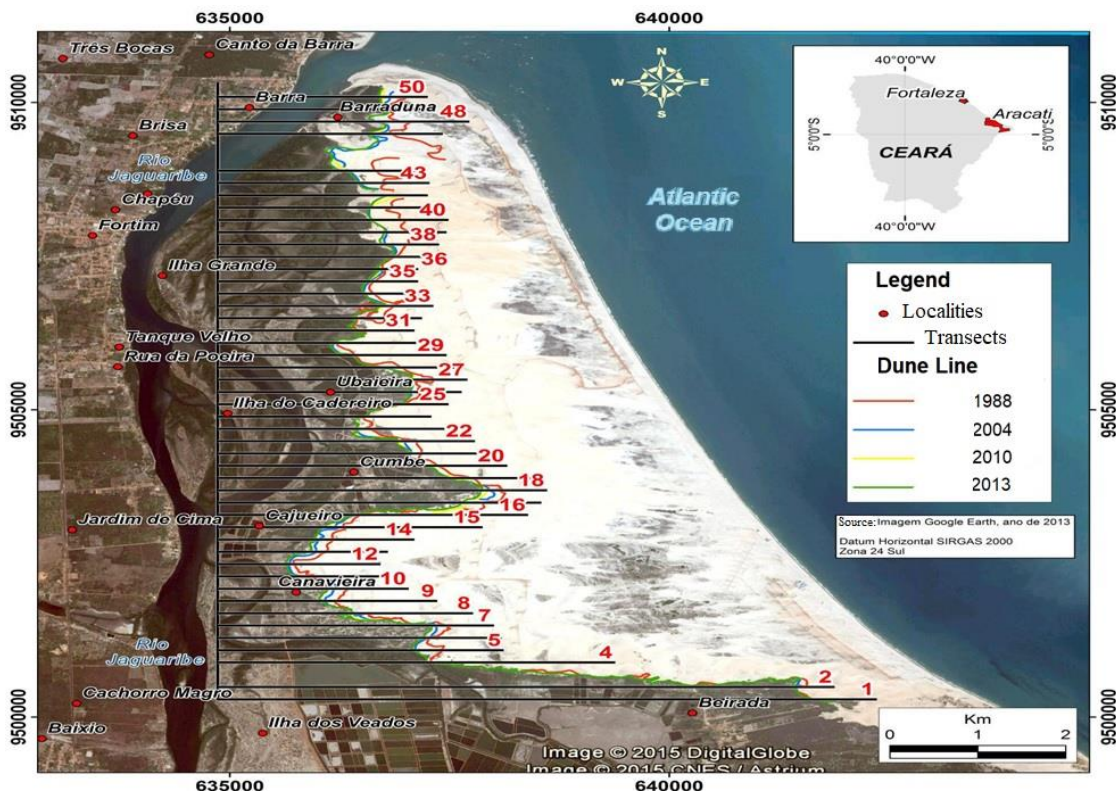


Fig. 5 Location of the transects made in the dunefields of Canoa Quebrada, in order to calculate the rates of migration of the dunes

The value that each transect calculates matches the given point of the dune. Therefore, the migration rate of a dunefield can be acquired by calculating the average of all transects.

The precipitation, temperature and wind speed data were collected in the Brazilian and Ceará State weather centers, at the meteorological station of Aracati City, 30 km from the study area. For the precipitation and temperature, monthly raw numbers were obtained at the Ceará State Meteorological and for Water Resources Foundation (FUNCEME), and statistics were made to give the annual averages for the time series analyzed. For the wind, raw monthly data was collected in the Forecast Weather and Climatic Studies Center of the National Institute of Spatial Research (CPTEC/INPE), and statistics were produced to attain the annual average numbers for the time series analyzed. There was no available wind data for the years 1988 and 2004.

For the physical recognition of the study area, as well as to evaluate the impact of tourism and turbine-wind plants in the natural dynamic, fieldworks were made in the dunefields, using a dune buggy. In addition, one day of navigation was done in a fishing boat in the channel of the Rio Jaguaribe, to identify the eventual impact of the migration of transgressive dunes toward the mangrove forest. The field trips took place in the years 2016 and 2017.

RESULTS AND DISCUSSION

The dune migration rate of the Canoa Quebrada dunefield obtained within 25 years is shown in Figure 6. This value was approximately 7.25 m/y. The greatest migration rate obtained was 18.4 m/y (transect 39, see Figure 6), while the lowest was 0.5 m/y (transect 2, see Figure 6). This migration rate appears to be much lower than those set for other sectors of the coastal zone of Ceará state and other states of Northeastern Brazil, as indicated by Maia (1993), Jimenez et al. (1999), Carvalho (2003), Castro (2005) and Carvalho et al (2006), Carneiro et al. (2012) and Santos and Santos (2015).

In the 1988-2004 period, the largest averages of migration rates showed values of the order of 9.3 m/y. In the spaces of time between 2005-2010 and 2011-2013, there was a decrease of the average rates of dune migration. In the period of 2005-2010, the average rate was approximately 3.5 m/y, and in the last interval, only 1.8 m/y.

The relationship between migration rates and the annual precipitation in the dunefields in the analyzed intervals is shown in Figure 7. The highest rainfall occurred in the period of 2005-2010, exceeding 1,000 mm/y. Much less rainfall occurred in the 2011-2013 period, reaching 600 mm/y. Comparing the intervals 1988-2004 and 2005-2010, there was a decrease in the average migration rate of the dunes while there was an increase of atmospheric precipitation. This confirms the normal behavior of dune mobilization, presenting a lower rate with the increasing rainfall. However, it appears that in the interval 2011-2013, even with decreased annual rainfall, there was not an increased migration rate of the dunes. Instead, the migration of the dunes for this time interval was also lower.

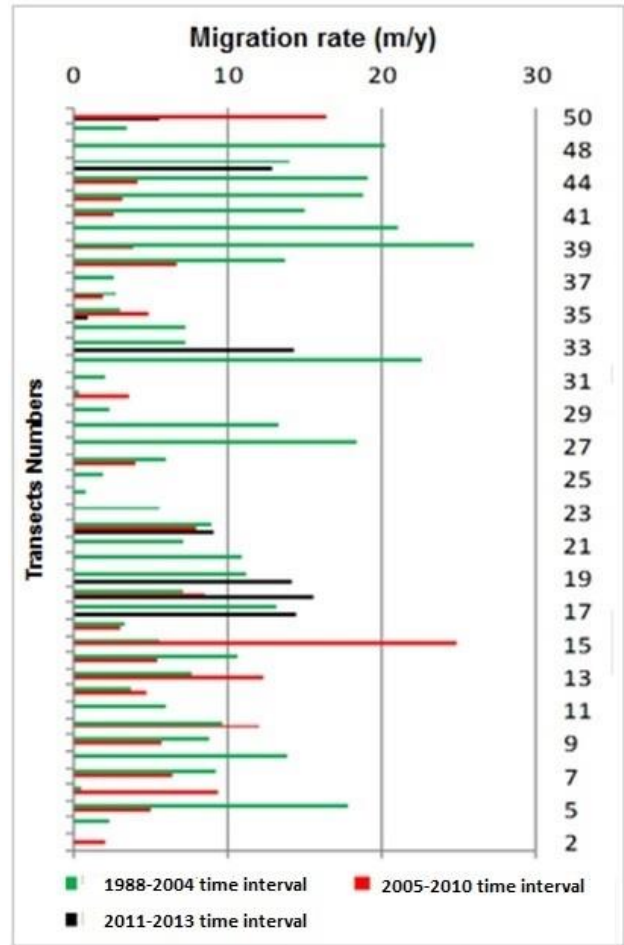


Fig. 6 Rates of dune migration in Canoa Quebrada for the studied time series

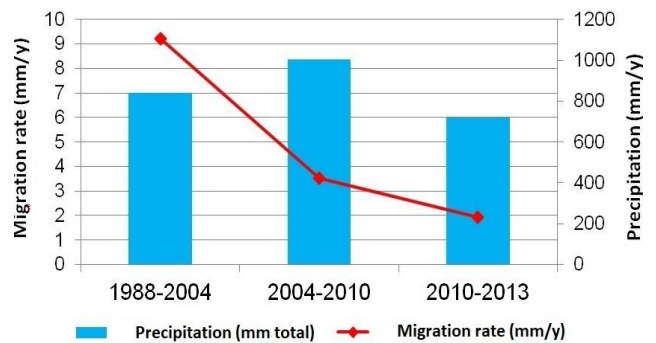


Fig. 7 Rates of migration and intensity of precipitation in Canoa Quebrada for the studied time series

Thus, the data in relation to the Canoa Quebrada Beach for the last time interval seem to contradict the relationship between the decrease of annual rainfall and increase in the average rate of dune migration, as seen in Figure 7. What is evident in the data of Canoa Quebrada is the occurrence of decreasing migration rates for the most recent time series.

The annual average wind speed obtained for Canoa Quebrada is below the speed measured in other parts of the Ceará State coast in previous decades: it was of the order of 1.45 m/s in 2010 and of 1.65 m/s in 2013 (CPTEC/INPE, 2015). The short interval of time of these data is not enough to affirm whether it is a systematic or just an eventual situation.

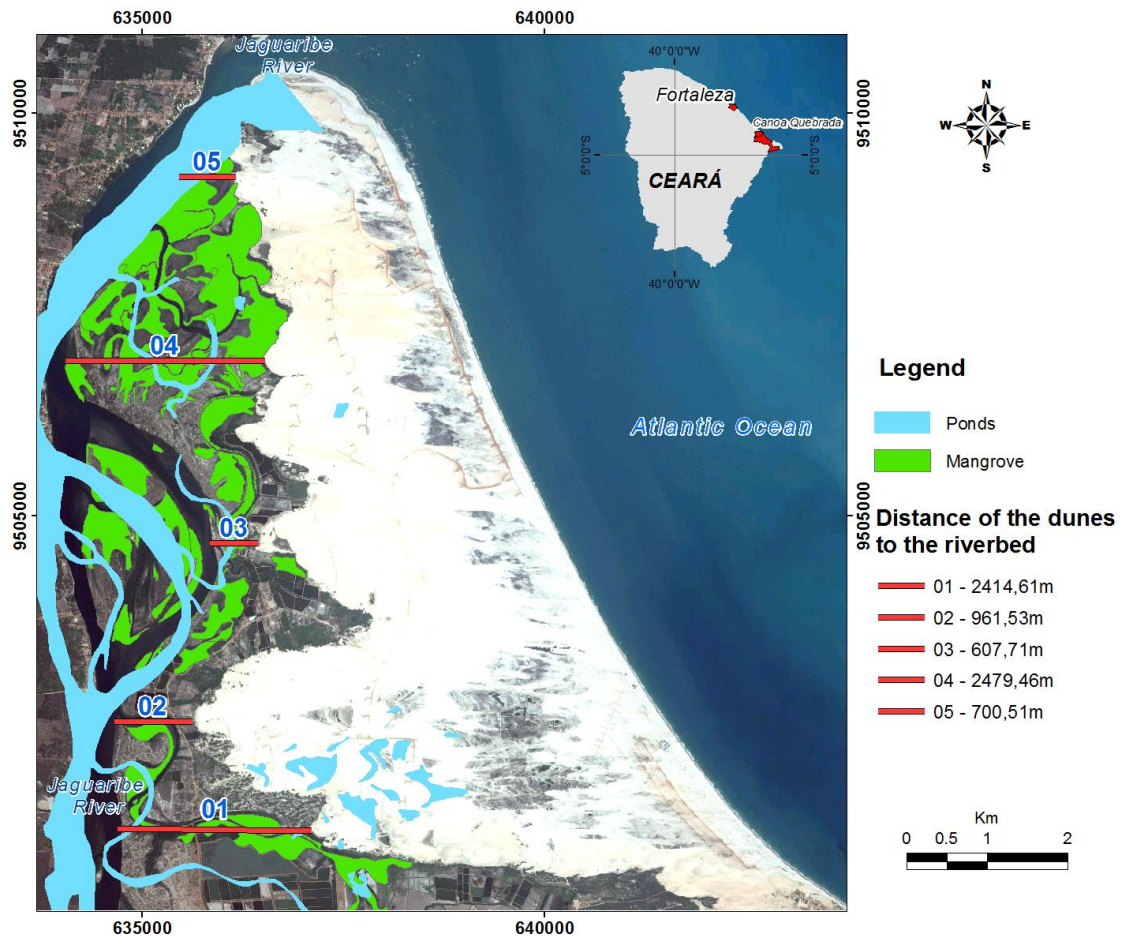


Fig. 8 Distances from the lee face of the mobile dunes to the Jaguaribe River estuary situated at the west segment of Canoa Quebrada coastal area

The mobile dunes of Canoa Quebrada migrated in the direction of the fluvial plain of the Jaguaribe River. Figure 8 shows the current average distance of the lee face of the dunes up to the riverbed. This distance is 1,432 m on average. The farthest point (04) measures 2,479 m, while the nearest (03) lies at 603 m.

During parts of the Holocene, the mobile dunes of Canoa Quebrada fed the Jaguaribe River with sediment. The river, in turn, probably deposited the sands in the ocean through its near mouth. Thus, the coastal sedimentary budget should have some sort of balance: the sediments would be transported by the action of winds from the beaches to the coastal zone's interior. Part of this stock would go back to the ocean through the bypass of dunes in headlands and by the supply of rivers. The sediments returned to the ocean by rivers would feed new beaches downstream, creating a retro-feeding mechanism capable of ensuring the balance of the shoreline and the control of coastal erosion.

With decreasing migration intensity of the dunes toward the river in the Canoa Quebrada coastal area, the amount of aeolian sand that fed the river flow became smaller. According to the average distance of the sliding face of the dunes to the river, and if the current aeolian regime continues, the dunes would take about 198 years to reach the riverbed, or 84 years, considering the nearest point. Thus, the sediment yield

to the ocean by the Jaguaribe River is certainly decreasing, which may be contributing to the growth of the coastal erosion that occurs in the beaches downstream of the river mouth. This erosion has been detected by Morais and Pinheiro (2011), who also considered the role of damming of the river in the last decades, as well as other occupation of the fluvial-marine plain by social activity, such as shrimp farms.

The considerable decrease in the migration rate of the dunes in Canoa Quebrada in the last decade, as measured, can also result in part from the forms of land use and occupation. Indeed, since mid-2009 wind turbines are being installed by private investors in the dunefields of the study area, as allowed by government, aimed to produce wind energy for regional consumption (Fig. 9).

For the installation and maintenance of the wind power plants, the installation of a network road for access was necessary, as well as the adoption of measures to protect the base of the structures from burial by sand and wind erosion. Therefore, a process of artificial fixation of sand began, using straw (Figs 10 and 11). The migration speed of the dunes was certainly altered to lower values with the implementation of containment techniques for mobile sands. Indeed, from 2010, the dunes presented little annual migratory movement, as identified by the analysis of satellite images. Nevertheless, the wind

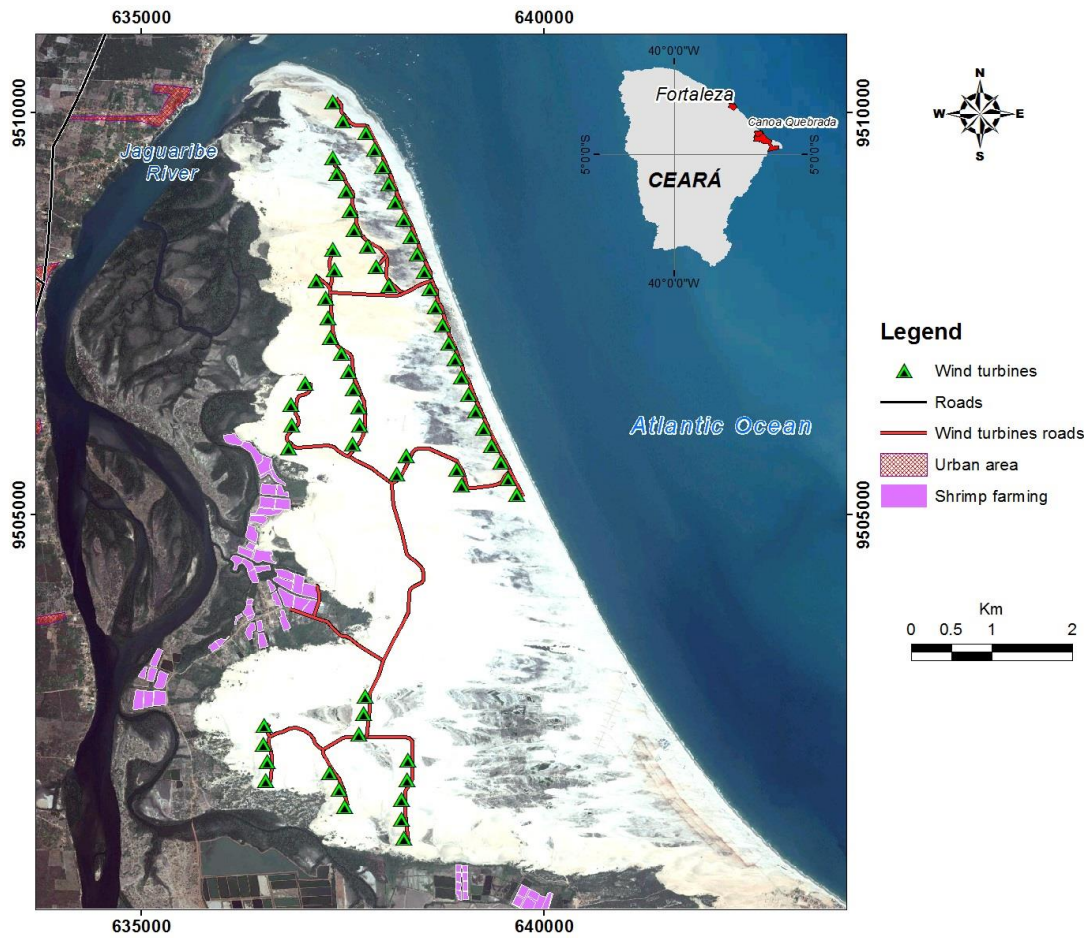


Fig. 9 Map of use and occupation of the study area, showing the location of wind-turbine plants

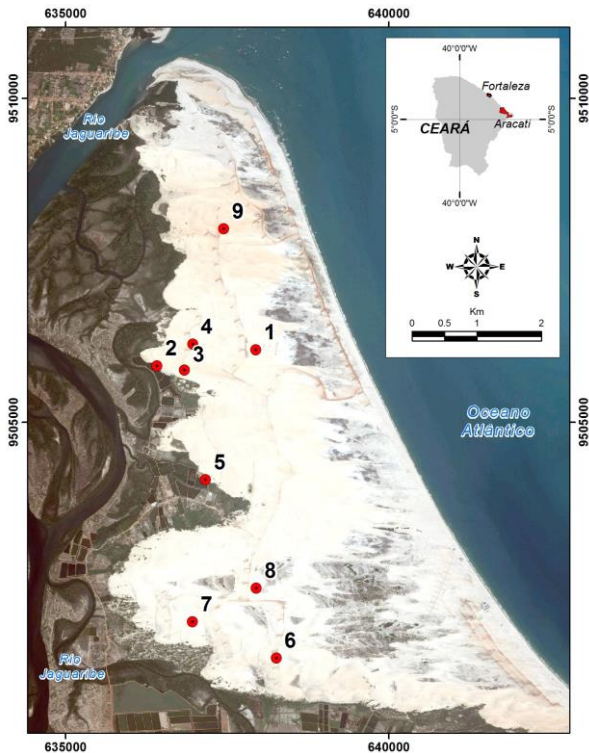


Fig. 10 Location of the introduction of straw to promote the fixation of the mobile dunefield of Canoa Quebrada, in order to protect the aeroturbines from burial by the sands and from aeolian erosion

speed was a little higher for the years 2011-2013, as shown in Figure 6.

The fixation of the mobile dunefields of Canoa Quebrada for the purpose of protection of the plants for aeolian energy is not the only threat to the dunefields and to the APA there. The opening of circulation routes to facilitate the traffic of buggy type vehicles, which carry tourists on the dunes, has to be mentioned (Figure 12). The village of Canoa Quebrada is one of the most important tourist destinations of the state, and is national and world renowned. The tourism flux is intense, and the traffic of buggies is considerable. This can also be a factor in the compaction of sand and of the reduction of the dune migration rates.

Dwindling sediments already present in the riverbed due to the construction of dams (around 30,000 tons of sediment annually retained: Morais and Pinheiro, 2011), particularly the large dam “Castanhão” at the end of the 1990s, the additional decrease of intake sediment caused by decreased dune migration in Canoa Quebrada on the riverbed possibly will result in non contribution of sediments from the Jaguaribe River to the ocean. It is considered here that without sediments, and taking into account the littoral dynamics of the study area, the river runs the risk of having its mouth barred by the construction of sand barriers formed by sand coming from the ocean, deposited by the action of waves and longshore drift.

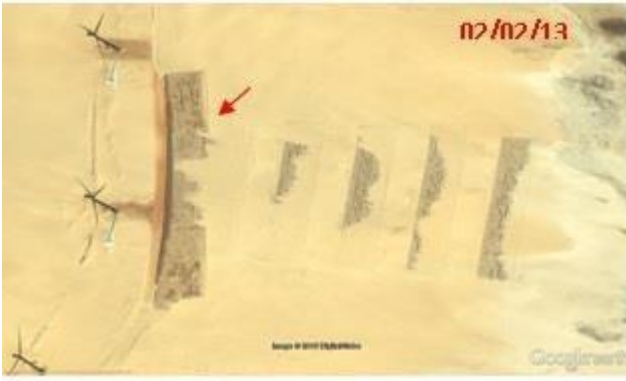


Fig. 11 Dunes fixed by straw in the coastal plain of Canoa Quebrada. (Source: Google Earth)



Fig. 12 Unpaved road (arrow) built on the mobile dunefields to allow the use of dune buggy vehicles, in order to answer tourist demands

CONCLUSIONS

The research synthesized here indicates the occurrence of a low annual average migration rate of the mobile dunes along the coastal plain of Canoa Quebrada Beach within 25 years, between 1988 and 2013. In addition, it appears that this reduction was increasing at the end of 2013. The migration rates (with minimal of 1.45 m/y) are considered lower when compared to the other sectors of the northern Brazilian area, as indicated by Maia (1998), Jimenez et al. (1999), Carvalho (2003), Castro (2005), Carvalho et al. (2006), Meireles (2011), Carneiro et al. (2012) and Santos and Santos (2015).

The data also showed a low annual wind speed, despite the decrease in precipitation in the last five years, which is the normal trend in the Brazilian northeast. The decrease in precipitation illustrates the great drought embracing the northeast region in recent years, through the action of El Niño. Such a situation seems to disprove the idea that the El Niño action increases the migration of dunes in the coastal zone of Ceará State, as indicated by Maia et al. (2005).

On the other hand, the low average migration rate of the dunes along the coastal plain of Canoa Quebrada, as identified in the data presented here, is clearly due to the low intensity of the wind in the area. Indeed, even with the decrease in precipitation, the migration rate did not increase between the observed time intervals. This seems to indicate that the main element responsible for dunes migration is wind speed. The installation of straw in some segments of the dunefield also contributed to a lesser rate of dune migration. The moisture content present in the sands

resulting from precipitation and other elements of the natural environment such as the topography of the land and the geometry of the dunes seem to be secondary factors.

Despite the existence of an area of environmental preservation - APA - in the dunefields of Canoa Quebrada, it is clear that some activities permitted by public agencies are degrading the dune ecosystem. This is the case of the measures taken to ensure the maintenance of the turbines for wind energy installed in the dunefields, and the resulting compaction from traffic by tourist passenger cars. These activities, approved or known by the state and local public agencies responsible for monitoring and ensuring the local environmental preservation, clearly work against the integrity of the dunefields. They are also possibly responsible for the lower rate of dune migration in the last analyzed interval of time.

Together, the natural dynamics and the dynamics induced by social activities in the coastal area of Canoa Quebrada have pointed to a virtual stabilization of the local dunefields, because of the increasing decline of the migration rates of the dunes. This may have regional implications, such as the lower contribution of aeolian sand to the sedimentary budget along the east coast of Ceará State. This stabilization can result in alterations in hydraulic and sedimentary dynamics of water resources coupled to the dune system, which can produce a magnification of the coastal erosion underway downdrift of Canoa Quebrada Beach. These findings should be incorporated into integrated coastal zone management strategies for the area, especially those associated with coastal erosion and preservation of the environment

Acknowledgments

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EVALUATION OF POTENTIAL RESERVOIR DEFICIENCY DUE TO CLIMATE CHANGE, KESEM KEBENA DAM, ETHIOPIA

Melese Chanie Shumie*

Civil Engineering Department, College of Engineering, Debre Berhan University, Block 24-558 Tebase, Kebele 09, St. Gabriel Church, 445 Debre Berhan, Ethiopia

*Corresponding author, e-mail: kelem.meles@gmail.com

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Abstract

Flood is an excess inundation of water on a surface and difficult to manage. The flood occurred in previous decades of Afar region of Ethiopia, consequently, leads to the death of human beings, destruction of infrastructures, an annihilation of massive hydraulic structures, and downstream properties. The main responsible factors for the flood incidences of the region are climate change, global warming, deforestation, and desertification. Climate change, however, is the foremost reason of increasing flood hazard. To coincide with this, hydraulic structures are designed based on the previously recorded flow data of a river. In Ethiopia, numerous earthen dams are constructed. The water storage capacity of dams is determined by the appraised flood of the upstream catchment: however, when the catchment flood increases due to climate extremes, the constructed structures cannot carry and going to demolish. The extra water that rises due to climate change from the catchment has to be removed before joins to the reservoir. This study has evaluated the potential reservoir deficiency of Kesem Kebena dam due to climate change. The study has comprehended different methods based on scientific criteria and selects the appropriate measure. As per the research output, the excess water that will arise from the catchment and add to the reservoir can be controlled by diversion floodways (Emergency spillways). The study has determined the amount of excess flood join to the reservoir for the excess rainfall incident month (August) for 100 years return period. Its magnitude is $85.76\text{m}^3/\text{s}$. The emergency spillway is the best means to divert such unwanted water before joining to the reservoir. Its hydraulic design is discussed in the study.

Keywords: Climate change, Kesem Kebena Dam, Reservoir, Prioritization, Emergency Spillway

INTRODUCTION

A flood is an overflow of a large volume of water on normally dry land beyond its normal limits (Salas et al., 2014). It is a natural phenomenon and nobody can preclude (Shaw, 2005). The floods on a catchment join to streams, channels, and rivers. The flow of these courses are recorded and documented for a certain year (Chow et al., 1988). Then, the documented and forecasted flood data are expedient to design hydraulic structure constructs on a river.

Climate change, an uncertainty of flood estimation methods, global warming, deforestation, desertification, data constraint, and soil degradation are the main features for the incident of an excess flood (Onwuka and Ikekpeazu, 2015).

As it is well known, the foremost governing factors used for hydraulic structure design are a maximum flood, project cost, and susceptibility to flooding, intended purpose and location (Botto et al., 2014). The above-mentioned features have prominent influence and shall be considered while designing water structures. Most of the riverine constructions in Ethiopia are planned and built by starved of bearing in mind of these features (Asfaw et al., 2014).

Hydraulic structures like earthen dams are susceptible to overtopping (Garg, 2006). As soon as the reservoir is entirely full it cannot tolerate tallying of extra and unwanted water to the reservoir. This surplus water is

going to over top the dam. The extra water endangers the structure and the hydraulic stability of the dam. A dam intends to be stable during construction, end of construction and in its service years (Arora, 2012). Suitable and appropriate measurements and solutions shall be considered in advance before a superfluous flood develops and makes problems.

Ethiopia is one of the largest developing countries in East Africa. Its topographical characteristics have made the country pretty vulnerable to floods (Abaya, 2008). The flood occurrence in different regions of the country leads to destruction of infrastructures system and damage to life. As per the Abaya's 2008 climate change study report, climate change is the major development challenge of the country. It has a significant impact on the incident of excess water (Abaya, 2008).

For several years, floods have occurred in different areas of the country. 2007 in Dire Dawa and South Omo, 2014 in Kemisse and 2017 in Meteka were the dangerous flood incidents which caused the deaths of dozens of people (Haile et al., 2013). In particular, the Meteka flood was the near year event and affected the displacement of more than 3,000 people from their home. The incident was captured as a photo as shown in Fig. 1 a) and b). It is located downstream of the study area.

Enormous water construction projects have been completed in different areas of the country (WWDSE, 2006). Most of them are multi-purpose dams and are

vulnerable to flooding. Among these, Kesem Kebena dam project was designed to supply irrigation water for a 20,000 ha land. In 2008 the Kesem Kebena Dam upstream catchment flood hazard demolished a 35m high dam at Kesem River. The total cost of the dam was two million US dollars by the time.



Fig. 1 a) Flash flood devastating Meteka town of afar region of Ethiopia in July 2017, b) the communities were displaced from their village

Effect of climate change for flood intensification at the research area was not scientifically studied before: however, scholars have investigated and quantified

climate change influence on other similar catchments. As stated by Wobus, et al., it has a significant effect to make an excess flooding. Climate change consequences a rise of 25% flood magnitude for 10 and less years return periods. It also makes 50% rise for 15-30 years return period and 67% flood magnitude increments for 100 years return periods (Wobus et al., 2017). Climate change is, even, worthy on the augmentation of floods for longer return periods.

Structures built across rivers are especially vulnerable to floods (Ranghunath, 2006). Potential damage can be decreased by structural and non-structural, hydraulic measures (Suykens et al., 2016). Fundamental structural hydraulic measures are: confining flood banks, river bed character improvement, flood diversion through floodways, reservoir storage improvement and cascade dams (Hudson and Harding, 2004). Whereas, the non-structural hydraulic measures include performing land use practice and soil conservation on flood plains, proclaim dam safety guidelines, adaptation of a flood warning system, community educations and geophysical information system (Hudson and Harding, 2004). These two itemized methods and their lists are aid to control both expected and excessive floods. It is unlikely to use all of these measures for a specific site. Therefore, the prioritization of measures and scientific studies are very vital.

There are many hydraulic flood controlling methods. All of them are not necessarily significant for a specific site. Prioritization of measures for a dam site is very important. The question of when and where the measures appropriateness is answered by observing and assessing previously studied substantial scientific papers.

The study discusses intended hydraulic measures and set its ultimate solution. Measures are appraised and discussed based on precise criteria. The criteria are implementation cost, construction simplicity, appropriateness to control flooding, durability, efficiency, and the place where the measures are located with reference to the structure (Stephens, 2012). The detail

Table 1 Structural flood controlling methods evaluation and selection

Measures	Advantages	Disadvantages	Economic Issues
Confining the flow between high banks	Important for protecting an area from over bank floods	It doesn't intend to decrease the due surplus water joins to the reservoir	Costly
River bed character improvement	Retard channel flood during its tide. It signifies flood by reducing its speed and increasing its storage volume	Changes the existing ecosystem and ecology of the river. It is not critically important to protect a downstream structure from excess water.	Less significant
Diversion floodways	Important to preserve the dam from overtopping and demolishing	Needs appropriate saddle point to be effective	Moderate
Improve reservoir storage capacity	It helps during dam construction	Its use is inhibited for full reservoir condition.	Costly
Cascade dams	The measure constructs at the upstream side of the flood prone area.	Constructing a dam for protecting other dam from flood hazard alone is illogical.	Costly
Adopting Soil Conservation	When the upstream catchment is conserved, the amount of flood becomes retarded.	The upstream catchment of the study area is not ominously important and not significant to soil conservation.	Less significant

measures appraisal and selection is done based on the listed out parameters of Table 1. The evaluation is done qualitatively for each measure’s advantage, disadvantage and economic issues. From the mentioned measures in Table 1; diversion of a flood through floodways, channel character improvement and soil conservation did not need more construction times, resources and crews. The remaining measures, i.e. confining the flow between high banks, providing a temporary storage reservoir, and improve the storage characteristics of the dam reservoir; however, needs large crews, resources and times. If the intention is to reduce certain percentage of flood these laterally mentioned methods are not significantly important.

The prioritized flood controlling measures at the dam reservoir is the first mentioned methods. But, the last two are not significantly important, i.e. river bed character improvement and soil conservation. Terrace and planting of trees conservation measure were there at the reservoir upstream catchment but the flood occurred and demolished the 35m high dam. From this, it is understood that even if the measure is already exercised, it was not critically significant. River bed character improvement has little significant and it has a negative impact in changing the ecosystem and ecology of the river.

As per the above explanations, all measures have specific aptness and snags. Therefore, thinking ahead about climate changes and propose diversion floodways is very important. Eventually, diversions of a portion of flood through floodways are the best prioritized flood controlling measures to protect earthen dams from excess flood (Cowin and Bardini, 2011).

This study evaluated the potential deficiency of the reservoir of Kesem Kebena dam due to climate change and designed appropriate structural hydraulic measures for controlling surplus flood water. In general, the research targeted to protect constructed earthen dams from excessive and unconsidered flood hazard throughout its service years.

STUDY AREA

The study focused on the Kesem Kebena Dam site (Fig. 2). The site is located in Kesem catchment (Fig. 2 c)), which is a sub-catchment of Awash Basin (Fig. 2 a) and b)) and located between altitudes of almost 3,471m to 870m above sea level (Fig. 2 b)). Its latitudinal and longitudinal directions are within 9°05’18”N 39°08’26”E to 9°08’56”N 39°53’03”E. The upstream catchment to dam site covers about 3,135km² (Fig. 2 c)). The length of the river up to dam axis is 230km (Fig. 2 c)).

The dam site experiences a typically tropical semi-arid climate with rainfall range of 350mm to 600mm per annum. Temperature varies from mean minima of 15°C and 21°C to mean maxima of 23°C and 38°C in December and June respectively. Mean relative humidity is lowest in January, 36% and highest in August 58%. Mean daily sunshine reported on an annual basis is 8.5hours.

The catchment experiences from cold to hot weather conditions at its lowland and highland areas respectively. Its rain range falls between 350mm in lowland arid areas to 1,500mm per annum at highlands. The land use condition of the catchment mainly includes: cultivated

agricultural land, bare land, grassland, forest land, and rural and urban settlements. The land use condition of the catchment percentage is shown in Figure 3. The most common soil types are 12% lithosols, 20% cambisols and 68% gypsisols (Paulose, 1989).

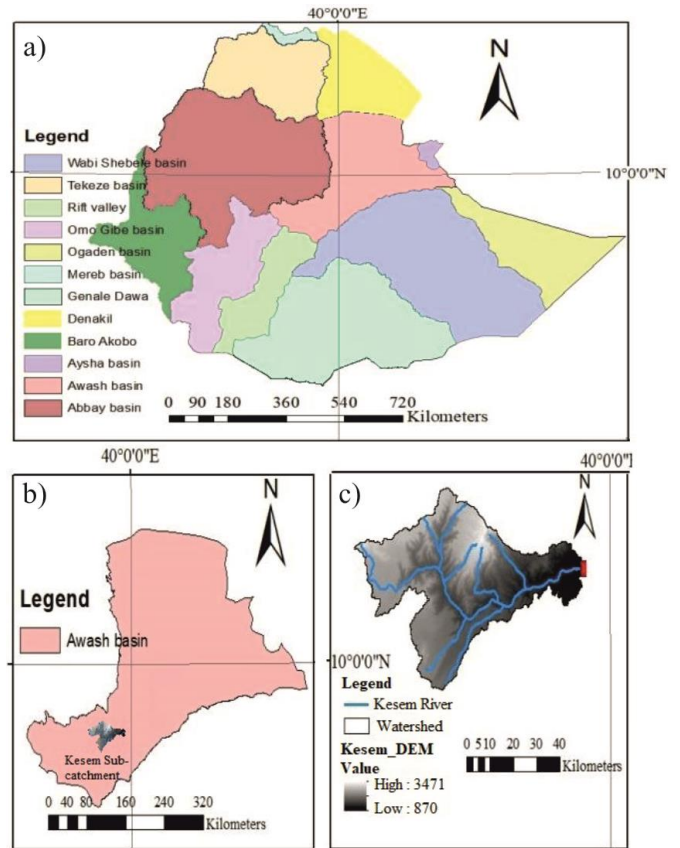


Fig. 2 a) Ethiopia River basins, b) Awash basin, c) Kesem sub-catchment

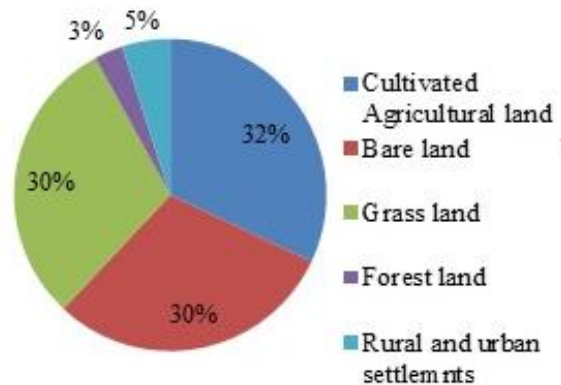


Fig.3 Land use condition of the catchment

DATA AND METHODS

Meteorological data collection

In this study 14 meteorological stations located in and around Kesem catchment were considered. The data of Sheno, Shola Gebeya, Balchi, Chefa Donsa and Alaltu were studied more intensively as they fell within the catchment upstream of the reservoir.

Thus, except July, August and September, as shown in Table 2, rainfall is highly variable. These dates are the

last 52 years monthly average rainfalls, shown in Table 2, (1966 to 2017) and higher than the 34 years monthly average data that the dam was initially designed, shown in Table 3, (1966 to 1999). It indicated and proved that there is a rainfall increment and the difference in percentage is expressed in Table 4.

Reservoir and spillway

The dam is zoned and constructed from earthen materials. Its structural height is 43m. The approximate reservoir capacity at its full supply level is 500 million m³ (WWDSE, 2006). Its fetch distance is 8,000m (WWDSE, 2006). The site has a concrete spillway, to spill the excess water from the reservoir, separated from the body of the dam. It is located at the right side of the dam reservoir. It has 1.5m effective discharge head (WWDSE, 2006).

The water discharges from the reservoir to the downstream command area is by 5m diameter tunnel. It is the water outlet for both downstream ecosystem and irrigation area. Hence, the average outflow from the dam pass through the tunnel is 11.74m³/s (WWDSE, 2006).

Maximum monthly rainfall

For this study a 52-years monthly average rainfall data was taken from Ethiopian metrological agency nearby stations and used to estimate the maximum extreme rainfall magnitude. To make the research reliable, 100 years return period is considered. The Gumbel’s method of extreme hydrologic event (Chow et al., 1988) is considered for maximum monthly rainfall scenarios. The method applicable to extreme hydrologic event is expressed as:

$$X_T = U + a Y_T \tag{Eq.1}$$

$$U = X - 0.5772*a \tag{Eq.2}$$

$$a = 0.7797*S \tag{Eq.3}$$

$$Y_T = -\ln(\ln(T/(T-1))) \tag{Eq.4}$$

where U = mode of distribution; Y_T = reduced variate; X = mean of the samples (Table 3); S = Standard deviation, K_T = frequency factors, T = return period, X_T = maximum rainfall magnitude for T years return period

Then the estimated maximum rainfall magnitude is probably happened in August because it is the maximum rainfall month as the climatological data shows. The remaining months maximum rainfall data were taken by taking the rainfall incremental percentage between the maximum monthly data from Table 2 and the computed maximum rainfall magnitude of August.

Peak inflow discharge

The rational method is used to estimate the peak runoff volume of the catchment. It is the inflow volume of the reservoir. The rainfall volume (in a million cubic meters), was computed using the following equation:

$$V = 1,000*CIA \tag{Eq.5}$$

Where; the rainfall volume (V) is expressed in a million m³, C is the average runoff coefficient, I = X_T is the computed maximum monthly rainfall of 100 years return period in mm, and A is the catchment area in km² (3,135).

The extreme rainfall magnitude is the rainfall record that will happen in a month. It is difficult and uncertain at what time and day it will happen within the month. So the appropriate and best scenario is keeping this maximum rainfall magnitude for the determination of monthly inflow discharge. That is why the research was conducted by assuming the rainfall magnitude at the maximum level throughout the month. The maximum inflow will happen at August as the rainfall trends indicated in Table 2 and 3.

The average runoff coefficient of the catchment has been taken from the topographic nature of the runoff surface (0.497). The land use and land cover of the catchment helps to know its runoff coefficient. The catchment has different types of land covers. Then, its average runoff coefficient is estimated by taking the weighted average of more than 30 small watershed land use of the upstream catchment with their corresponding runoff coefficient and area cover.

$$C = \sum_{i=1}^n \frac{(C_i * A_i)}{(A_1 + A_2 + \dots + A_n)} \tag{Eq. 6}$$

Table 2 Monthly Average rainfall data of the 14 rain gauge stations in the period of 1966-2017 (Source: Ethiopia Metrological Agency)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
RF (mm)	12.1	28.2	47.2	5.7	45.8	63.1	242.5	261.4	99.3	25.1	9.9	5.7

Table 3 Monthly Average rainfall data of the 14 rain gauge stations in the period of 1966-1999 (Source: Ethiopia Metrological Agency)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
RF (mm)	10.8	26.7	47	5.6	43.1	60	221.5	230.9	94.6	24.7	10	5.7

Table 4 Monthly Average rainfall data increment of the 14 rain gauge stations between the two investigated periods (1966-1999, 1966-2017) (Source: Ethiopia Metrological Agency)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
RF increment (%)	12%	6%	0%	2%	6%	5%	9%	13%	5%	2%	0%	0%

Monthly outflow volume

The outflow volume of the dam arises from its bottom outlet and/or main spillway. The spillway has effective length and height. Its maximum discharge is estimated by considering the full effective length, height and velocity (WWDSE, 2006). They are secondary data obtained from the hydrologic design report of the Kesem Kebena dam. The bottom outlet is also considered constant and taking the full flow through the 5m diameter tunnel. The research is done by taking the secondary data from hydrologic design report of Kesem Kebena dam report (WWDSE, 2006).

Monthly excess water volume

The monthly excess water joined to the reservoir is computed by considering the outflow from both the spillway and the bottom outlet (tunnel), inflow from the catchment and storage from the reservoir. The computation is made for each month starting from August. The calculation is assumed that the dam is full at the end of July before the start of the computation i.e. August. As the previous experience shows most of the Ethiopian earthen dams have been fully filled at the end of July. So it is better to start the simulation by assuming the dam is initially full.

$$V_m = I + S - O \quad (\text{Eq.7})$$

where: V_m : Monthly excess water volume, I : Inflow, S : storage, O : outflow

The spillway outflow volume is considered when the difference of monthly inflow and storage of the dam is greater than the total capacity of the reservoir and its bottom outlet. The maximum effective storage volume of the reservoir is 500 million cubic meters (secondary data from WWDSE) and its spillway design discharge is equal to 106.61 m³/s (secondary data from WWSDE).

The computation is made for 100 years return period because the other lower years discharge cannot exceed the discharge due to 100 years return period.

Emergency spillway design

These are spillways which provided for additional safeties of the dam, which not contemplated by normal design assumptions. The research site (dam) is already completed and providing its service. So, the researcher couldn't modify the main spillway design. Then, the proposing solution is diverting the excess water at the entrance of the reservoir using emergency spillway. Its crest is set at the maximum design water level of the dam. Its main purpose is to protect the dam against overtopping due to extreme flood conditions.

Spillway design computations

The height of the spillway above the ground level is the total height from the normal spillway level to its crest (2m). The surplus water volume is computed from the inflow, outflow, and storage simulation. The design discharge of the emergency spillway is computed using equation (8) and its effective length is computed by the equation (9).

$$Q = C * L_e * H_e^{3/2} \quad (\text{Eq.8})$$

Where: - Q is discharge in m³/s, C is the coefficient of discharge (1.8), L_e is the effective length of the crest of the spillway (m), H_e is the actual effective head including the head due to the velocity of approach

$$L_e = L - 2 * (N * k_p + k_a) * H_e \quad (\text{Eq.9})$$

where: L_e is crest effective length, L is net length of crest which is equal to the sum of the clear spans of the gate bays between piers, H_e is a total head on crest, including velocity head, N is number of piers, K_p (0.01) is a pier contraction coefficient and K_a (0.1) is an abutment contraction coefficient (Arora, 2012).

Ogee crest design

The shape of an ogee spillway depends upon a number of factors such as head over the crest, height of the spillway above the bed of the entrance channel and the inclination of the u/s face of the spillway (Garg, 2006). Several standard ogee shapes have been developed by a United States army corps of engineers and the vertical shaped ogee is most familiar and has the following set out (Fig. 4).

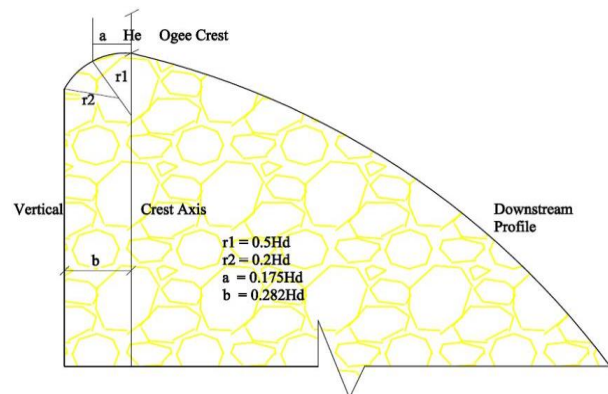


Fig. 4 Ogee spillway cross sectional profile

The downstream profile is drawn by the equation, $X^n = kH_d^{n-1}y$. Where: x and y are the coordinates of the points on the crest profile with the origin at the highest point called the apex, H_d : Design head excluding the head due to velocity of approach and k & n are constants which depend on the inclination of the upstream face whereas the upstream profile is drawn by using the parameters a , b , r_1 and r_2 . The spillway is uncontrolled at its crest.

RESULTS AND DISCUSSION

Maximum monthly rainfall

According to Equation 1 to 4 and Table 2, $U = 30.65$; $a = 69.5$, $Y_T = 4.6$. Then $X_T = 350.35$ mm, it is the maximum monthly rainfall magnitude as per Gumbel's method of extreme event distribution and will happen in August. The percentage increment of the 52 years average rainfall and the newly computed extreme event magnitude of August is 34.02%. This increment will help to arbitrarily fix the other months increment for inflow-outflow tabulation.

Computing excess flood volume

To obtain the monthly excess flood magnitudes, the monthly average rainfall data of 14 rain gauges were taken. As the result of the study shown in Table 5 and 6,

the dam cannot tolerate to carry the whole volume of water added to the reservoir in July and August. There is extra water in these months joins to the reservoir. The surprising thing, here, is that the dam, even, could not carry the volume of water in July and August produced by the current rain fall magnitudes (Table 5). It is a shock situation.

The dam was in danger at the end of July 2018 due to the symptom of overtopping since the dam was extremely full. The government decided and diverted a portion of water at the upstream side of the dam and it made the dam stable. The result of the study is an approval of that situation.

The situation is even grave when the 100 years return period extreme climate change conditions are considered. The surplus water for this return period is much extreme and immediate action is needed to control the condition.

As it is shown from Table 5 and 6, unwanted extra water is added to the reservoir in July and August. The designed emergency spillway benefits to remove this extra water from the reservoir. Plus, the spillway is designed by using the maximum surplus water originated in August. The study was conducted by assuming, this extra flood discharge will occur in certain days within the month. It is difficult to know the exact days of the month and the study has been conducted considering the maximum discharge throughout the month.

The maximum surplus design discharge (water volume) which is obtained by taking the current rainfall magnitude is $34.03\text{m}^3/\text{s}$ ($91.15 \times 10^6 \text{m}^3/\text{month}$). In the same procedure, the 100 years return period maximum surplus design discharge is $85.76\text{m}^3/\text{s}$ ($229.70 \times 10^6 \text{m}^3/\text{month}$) respectively. The computation is a yearly based simulation.

Ogee profile and hydraulic design

The provided extra spillway is vertical upstream face and ogee shaped. Its initial effective length was 18m. The maximum 100 years return period design discharge of the spillway is $85.76\text{m}^3/\text{s}$. The central pier which equally divides the spillway and carries the bridge is 1m thick and square in cross section. The adjusted coefficient of discharge of the spillway is 2.15. The coefficient is adjusted with effect of approach depth, head ratio, upstream face slope and downstream apron interference.

The spillway effective length and the head is computed using equation 1 and 2. Hence, its effective length (L_e) considering abutment and pier contraction effect is 16.6m and the effective head including the velocity head, H_e , is 1.76m. The velocity head of the spillway is 0.08m and small. So, H_d is 1.68m. The supposed spillway is vertical upstream face and $n = 1.85$ and $k = 2.00$. $X^{1.85} = 2H_d^{0.85}y$ and H_d is 1.68m, Then, $X^{1.85} = 3.11y$. The maximum value of y is equal

Table 5 The monthly inflow, outflow, storage and surplus water volume in million cubic meters for current rainfall magnitudes

Month	RF (mm)	Inflow	Available storage	Dam outlet	Main spillway	Temporary total available water*	Spill out water	Net available water**	Surplus
Aug	261.40	407.29	500.00	31.54	284.60	875.75	284.60	591.15	91.15
Sep	99.30	154.72	500.00	30.52	275.42	624.20	124.20	500.00	
Oct	25.10	39.11	500.00	31.54	284.60	507.57	7.57	500.00	
Nov	9.90	15.43	500.00	30.52	275.42	484.91	-	484.91	
Dec	5.70	8.88	484.91	31.54	284.60	462.25	-	462.25	
Jan	12.10	18.85	462.25	31.54	284.60	449.56	-	449.56	
Feb	28.20	43.94	449.56	28.49	257.06	465.01	-	465.01	
Mar	47.20	73.54	465.01	31.54	284.60	507.01	7.01	500.00	
Apr	5.70	8.88	500.00	30.52	275.42	478.36	-	478.36	
May	45.80	71.36	478.36	31.54	284.60	518.18	18.18	500.00	
Jun	63.10	98.32	500.00	30.52	275.42	567.80	67.80	500.00	
Jul	242.50	377.84	500.00	31.54	284.60	846.30	284.60	561.70	61.70

*inflow+available storage–dam outlet; **temporary total available water of the dam–spill out water

Table 6 The maximum monthly inflow, outflow, storage and surplus water volume in million cubic meters of 100 years return period rain fall incidents

Month	RF (mm)	Inflow	Available Storage	Dam outlet	Main spillway	Temporary total available water*	Spill out water	Net available water**	Surplus
Aug	350.33	545.84	500.00	31.54	284.60	1,014.30	284.60	729.70	229.70
Sep	133.08	207.35	500.00	30.52	275.42	676.83	176.83	500.00	
Oct	33.64	52.41	500.00	31.54	284.60	520.87	20.87	500.00	
Nov	13.27	20.67	500.00	30.52	275.42	490.15	-	490.15	
Dec	7.64	11.90	490.15	31.54	284.60	470.52	-	470.52	
Jan	16.22	25.27	470.52	31.54	284.60	464.24	-	464.24	
Feb	37.79	58.89	464.24	28.49	257.06	494.64	-	494.64	
Mar	63.26	98.56	494.64	31.54	284.60	561.66	61.66	500.00	
Apr	7.64	11.90	500.00	30.52	275.42	481.38	-	481.38	
May	61.38	95.64	481.38	31.54	284.60	545.48	45.48	500.00	
Jun	84.57	131.76	500.00	30.52	275.42	601.24	101.24	500.00	
Jul	325.00	506.38	500.00	31.54	284.60	974.84	284.60	690.24	190.24

*inflow+available storage–dam outlet; **temporary total available water of the dam–spill out water

to the spillway height (2m). The necessary values of x and y for drawing the spill way cross-sections are tabulated in Table 7. The upstream ogee profile parameters: a is equal to 0.29m, b is equal to 0.47m, r₁ is equal to 0.84m and r₂ is equal to 0.34m. The cross-sectional profile of the emergency spill way is shown in Fig. 5.

Table 7 The downstream ogee profile design (m)

Y	0	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00
X	0	0.87	1.27	1.58	1.85	2.08	2.30	2.50	2.69

CONCLUSION

Climate changes are aggravated conditions for excess flood incidence in a catchment. Their impact studies by different researchers and shivering in flood increment for longer return periods. Hence, the study has shown its discharge augmentation amount. The flood that occurred at Kesem catchment in 2008 was a flash flood. The catchment is very susceptible to flooding and in danger for the stability of the dam. It is impossible to prevent such floods whereas the flood can reduce their effect by providing control structures.

The design flood of a hydraulic structure constructs in a river can be estimated by analysis of stream flow data and/or rainfall based methods. But, there is no stream flow measuring devices at the river of the research site. So, the rainfall based flow estimation is the concurrent and the only means to estimate the river design flood. The average rational method provides an appropriate and reliable result for such scenarios from the rainfall based analysis methods since the others provide either exaggerated or less result.

The assessment of inflow-storage-outflow volume simulation by considering the current and future climate change impact is very important to know the situation of the reservoir. According to this, the study shows that the reservoir cannot tolerate the

surplus water for the coming 100 years. Therefore, the foremost thing that shall be done at the site level is implementing the prioritized flood control structure immediately.

All excess flood controlling structures are not necessarily important for a specific site. Then, it has to be scientifically priorities to select the best measure for a specific site. From numerous flood controlling structures, flood diversion through floodways is the best-prioritized flood control structures in the study area. Thus, the researcher selected emergency spillway for immediate action and the safety of the dam.

The emergency spillway has helped to remove excess water from the reservoir and safely save the dam from a hazard. The spillway is designed based on surplus water from the inflow-storage-outflow simulation of the reservoir. However, the study did not include its geotechnical and structural design.

The proposed structural flood controlling measure for Kesem Kebena dam is the best solution for the current risky flood conditions of the reservoir site. It is crucial to protect structures especially the main dam, which is mostly constructed from earthen materials, from the superfluous water. Then, the measure will protect it from an excessive flood. The provision of these bypass structures uses to pass flood at saddle points. Meanwhile, numerous saddle points are situated along the reservoir entrance. Fortunately, there is neither population nor as such vast properties found at the downstream side of the saddle point. The method is also appropriate for earthen dams which are susceptible to the flood.

The researcher concludes by recommending to conduct further modeling studies of the inflow-storage-outflow of the reservoir by taking different flood estimation methods. In addition to this, during the 100 years' service time of the dam, the sediment impact is not as such tolerable. So, further researches have to be conducted because it will reduce the effective storage of the reservoir.

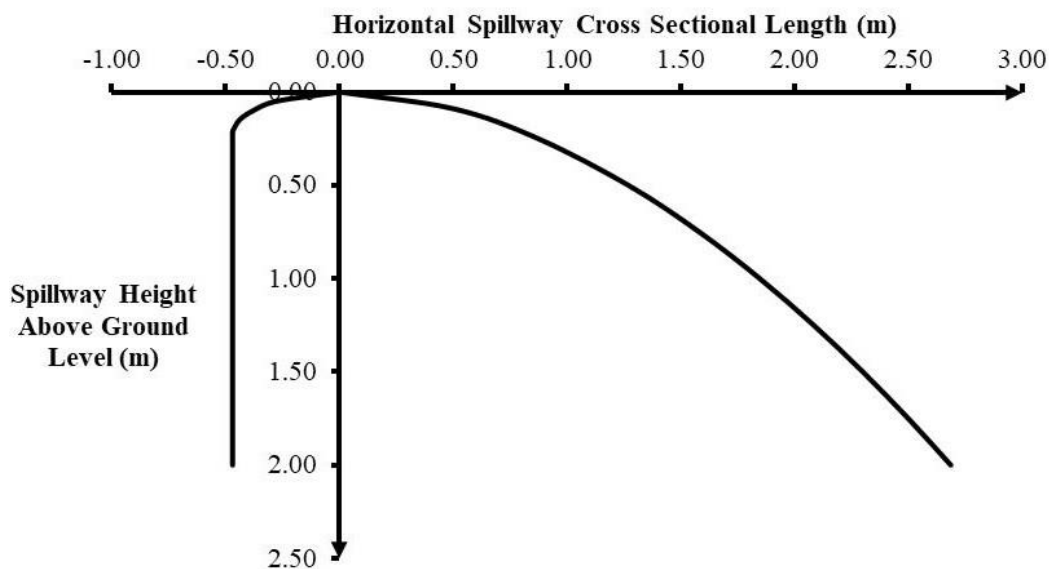


Fig. 5 The designed emergency spillway cross-sectional profile

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ASSESSING THE SPATIO-TEMPORAL PATTERN OF LAND USE AND LAND COVER CHANGES IN OSUN DRAINAGE BASIN, NIGERIA

Eniola Damilola Ashaolu*, Jacob Funso Olorunfemi, Ifatokun Paul Ifabiyi

Department of Geography and Environmental Management, Faculty of Social Sciences, University of Ilorin, PMB 1515 Ilorin, Nigeria

*Corresponding author, e-mail: damash007@yahoo.com

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Abstract

Over the years, Osun drainage basin has witnessed tremendous increase in population, and urbanization that have changed the landscape of the area. This study evaluated the spatio-temporal pattern of land use/land cover change (LULC) in the study area, and made hydrological inferences. Landsat imageries were acquired from USGS-EROS satellite image database for the period 1984, 2000 and 2015, while the Digital Elevation Model (DEM) was obtained from Shuttle Radar Topography Mission (SRTM) of the National Aeronautics and Space Agency (NASA). Supervised image classification using the Maximum Likelihood Algorithm in Erdas Imagine was adopted to classified the land use/land cover of the study area into seven classes. Elevation, aspect and slope of the study area were processed from DEM using ArcGIS. Modules for Land Use Change Evaluation (MOLUSCE) plugin in QGIS was used to simulate the basin future LULC change, using change driving factors of population, elevation, aspect and slope of the study area. There was about 234% increase in built up areas and 89.22% in crop/shrubs between 1984 and 2015. The most significant decrease in LULC occurred in forest (58.75%) and wetland (84.69%) during this period. The predicted future LULC change suggests that only about 12% of the basin will remain under forest cover by the year 2046. The results underscored the increasing anthropogenic activities in the basin that influenced recharge rate, surface runoff, incidences of soil erosion, etc., in Osun drainage basin. The planting of the lost native trees was recommended for the sustainability of the basin's ecosystem.

Keywords: Land use/land cover, spatio-temporal, change detection, Osun drainage basin

INTRODUCTION

The existing land use/land cover (LULC) in a region and the previous impacts of the earlier LULC change still operating in the system determines the response of the ecosystem to disruption in LULC (Martin et al. 2011). The change in LULC of a region, particularly increase in built up areas advertently or inadvertently alters the hydrological processes which include change in runoff pattern, modification of peak flow characteristics, alteration of water quality, etc. (Noorazuan et al., 2003). In fact, changes in land use may have unintended negative impacts on the hydrological regime of a drainage basin, thereby increasing the chances of flood occurrence and also reducing the dry season flow (Lorup et al., 1998). Studies have reported that change in land use and land cover can influence surface runoff, infiltration, groundwater recharge, water quality and supply in a drainage basin. Depending on the degree of change, overland flow can be increased or reduced, infiltration and recharge can also increase or reduce (Ziegler and Giambelluca, 1997; Turner et al., 2001; Butt et al., 2015; Ashaolu, 2018).

In the views of Ashraf (2013) and Butt et al. (2015), land use/land cover change in a drainage basin include rapid urbanization, deforestation and afforestation which endlessly influence the water budget; and the type and magnitude of surface and subsurface water exchanges. Thereby affecting drainage basin ecology and their

various benefits to man. Nevertheless, enhanced water preservation schemes can be articulated through the appropriate identification of the spatio-temporal variation taking place in a drainage basin and the relationship between the various components of the basin (Ashraf, 2013; Butt et al., 2015). Therefore, assessing the spatio-temporal pattern and changes of land use and land cover at drainage basin level is essential to the management and planning of the drainage basin water resources (Butt et al., 2015) and land use allocation that will not jeopardize the basin ecosystem in particular.

Over the years, Osun drainage basin which is one of the two major drainage basins in the southwestern Nigeria has witnessed tremendous increase in population, farm settlements, urbanization and emerging cities which have changed the landscape of the drainage basin. The land use pattern within Osun drainage basin include land use for residential/settlements, built up areas, bare rocks, soils surfaces, farmlands (annual crops/shrubs and agroforestry/secondary regrowth), vegetation and water bodies. Over two decades ago, Salami (1995) reported that the increasing population density coupled with the long history of agricultural colonization of some parts of the basin has resulted to substantial alteration of the basin's natural environment. Salami et al. (1999) also reported that the natural vegetation of so many parts of the basin has been replaced by secondary forest or perennial and annual crops.

Therefore, the vegetation of the area can be described as derived savannah characterized by gallery of forest along stream sides and tall grasses with scattered perennial trees over land. The basin is covered by secondary forest and the derived savannah mosaic predominates in the northern part. Originally, almost all parts of the basin had a natural lowland tropical rain forest vegetation; but this has however, been replaced by secondary forest regrowth as a result of years of anthropogenic activities. However, relics of the old rainforest species are still found in some isolated areas. Some of the reasons for this change in vegetation are fuel wood production, road construction, clay and sand quarrying and traditional farming practices (Ifabiyi, 2005).

In recent years, studies on LULC in Osun drainage basin were carried out to understand the changing pattern of LULC in settlements therein and were for the purpose of urban planning (Salami, 1995; Salami et al., 1999; Akinyemi, 2005; Mengistu and Salami, 2007; Gasu et al., 2016) and not with the aim of understanding the implications of such LULC changes on the hydrology of the entire basins. These studies have suggested changes in LULC all over the basin which will no doubt influence the water budget. For example, Akinyemi (2005) discovered that the greatest percentage change in land use/land cover of the part of the basin that includes, Ilesha, Ijebu Ijesa, Imesi Ile, Otan Aiyegbaju, Igbajo Efon Alaiye and Oke-Messi, etc. were recorded on built up areas/roads (88.41%), while Agro-forestry/secondary regrowth decreased by 49.06% between 1986 and 2002. Similarly, Gasu et al. (2016) discovered that the urban/built-up areas in Osogbo, one of the major towns in the basin have increased by about 415% between 1986 and 2012.

In addition, Mengistu and Salami (2007) reported a significant conversion of natural vegetation cover to farmland and settlements between 1986 and 2002 in the upper part of the basin. The area covered by Savanna and high forest declined by 71.9 and 8%, respectively, while shrubs/farmlands and settlements/bare surface increased by 413.6% and 192.4%, respectively. All these studies attributed the change in the land use/land cover of the area to the rapid expansion of agricultural land as a result of change in socioeconomic system of the region, population growth, expansion of settlements, gold mining activities, fuelwood extraction, intensive biomass burning and illegal logging. It is noteworthy, that a study that attempted a LULC classification of Osun drainage basin was limited to the upper part of the drainage basin basically in the portion that falls within Osun and Ekiti States (Akinwumiju, 2015), and there is need to cover the entire drainage basin in order to fully understand the LULC change scenario in Osun drainage basin, Nigeria. The changes in LULC experienced in Osun drainage basin over the years will no doubt influence the hydrology of the basin. Therefore, understanding land use and land cover change in the basin will enhance planning and management activities within the study area. This study therefore evaluated the change in LULC of Osun drainage basin over the years and made hydrological inferences from the results of the change detection.

STUDY AREA

Osun drainage basin is located between latitudes 6°25'58.79" and 8°21'3.6" N and longitudes 3°47'34.8" and 5°10'55.2" E in the southwestern Nigeria (Fig. 1).

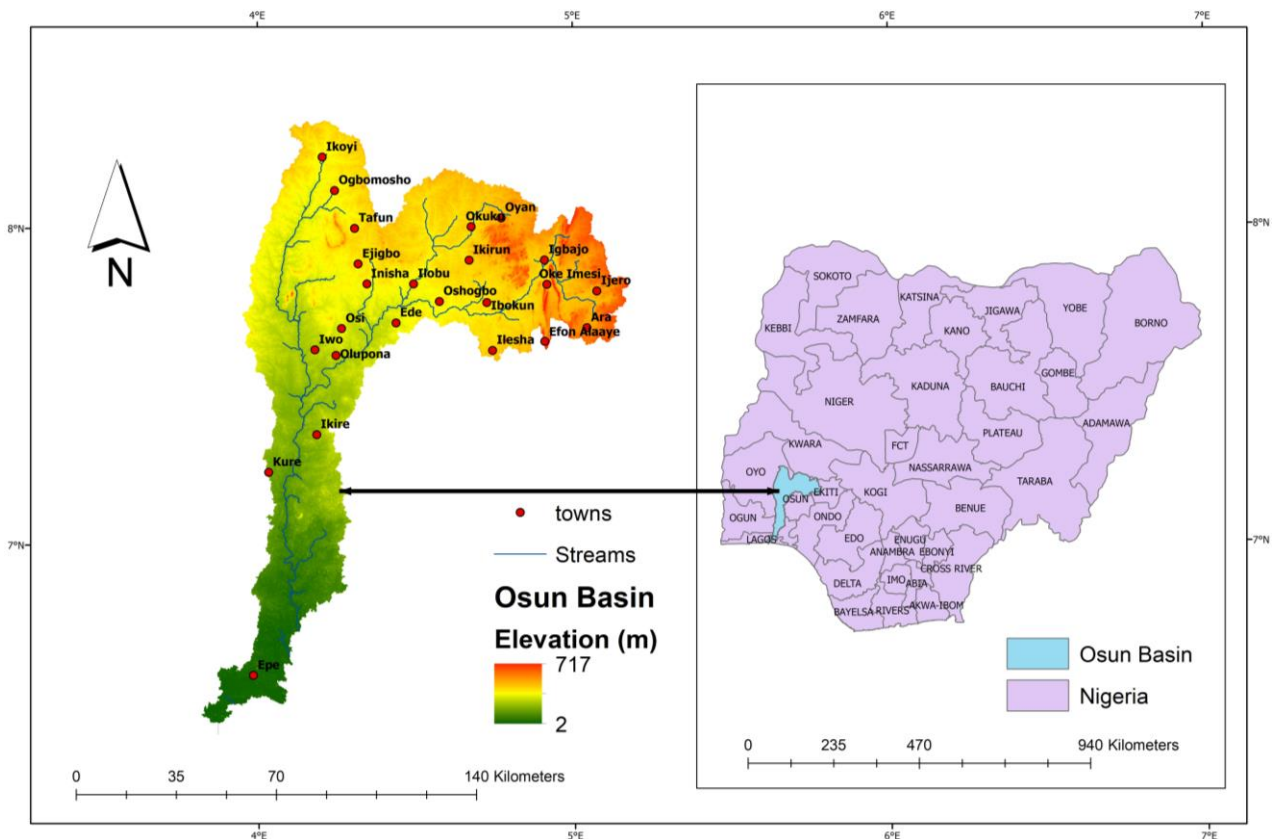


Fig. 1 Location and position of Osun Drainage Basin, Nigeria. Source: Modified form Ashaolu (2016)

River Osun which is the major river in the drainage system accents in Oke-Mesi ridge, about 5 km North of Effon Alaiye and flows North across the Itawure gap to latitude 7°53" and then deviates westwards via Osogbo, Ede and southwards to flow into Lagos lagoon (Ogun-Oshun River Basin Development Authority (OORBDA, 1982; Oke et al., 2013; Ashaolu, 2016). The basin climate is influenced by the movement of the Inter-tropical Convergence Zone (ITCZ), the quazi-stationary boundary that distinguishes the sub-tropical continental air mass over the Sahara and the equatorial maritime air mas over the Atlantic Ocean (OORBDA, 1982). The climate of the basin can be described as the tropical continental climate of Koppen Aw type humid tropical rainforest climate (Ifabiyi, 2005).

The months of February and March are the hottest in the basin and temperatures are high over the entire basin during this period. The mean annual temperature is about 30°C, which can varies depending on the location and time of the year (Ifabiyi, 2005). The basin is underlain by two types of rocks which are the Basement Complex rocks and the sedimentary basins (OORBDA, 1982; Oke et al., 2013). About 93% of the basin is underlain by the Basement Complex rocks, while the remaining 7% is sedimentary rock found in the southern part of the basin close to the Atlantic (Ashaolu, 2016). The soils in larger part of the study area belong to the highly ferruginous tropical red soils associated with Basement Complex rocks (Ifabiyi, 2005). The relief of the basin is generally undulating and descends from an altitude of about 700 meters in Oke Imesi area to 50 meters and below in areas around Epe and Ibeju Lekki in the southern parts of the basin (Ashaolu, 2016). The land use pattern within the drainage basin includes land use for residential/settlements and built up areas, bare rocks, bare surfaces, crops/shrubs, vegetation/forest and water bodies. The population distribution pattern of the basin is quite uneven. The urban population in the basin is larger than the rural population. Based on the 1963 population census of western Nigeria, the estimated population of the basin made by Ogun-Oshun River Basin Development Authority in 1980 was 4,281,000 and was estimated to be 12,046,145 in 2015 from 1991 population census using 3.0 percent growth rate for areas that comprises of rural and urban settlements in Nigeria (Ashaolu, 2018).

MATERIALS AND METHODS

Landsat imageries of the study area were acquired from USGS-EROS satellite image database for 3 epochs (1984, 2000 and 2015). Table 1 shows the type, path/row, date and characteristics of the satellite images acquired. The images of the years 1984 and 2015 were captured in December, while that of the year 2000 were captured in February. The disparity in the months was because February year 2000 was the closest month to December with all the four satellite scenes that covered the study area. It is important to note that vegetal cover from December to March in the study area are quite similar, hence it cannot affect the reality of the change detection registered in this study. The satellite images of 2015 are pansharpened using the panchromatic 15m band of Landsat 8 and all the other images were resampled into 15m pixel size from their original 30m resolution. The nearest neighbor resampling method was

adopted to resample the satellite images using ArcGIS 10.4. The study area falls within four different satellite scenes. The bands of each of the satellite image scenes of the three periods were first stacked in Erdas Imagine 2014. The four scenes for the years 1984, 2000 and 2015 were mosaic using the MosaicPro algorithm in Erdas Imagine 2014. The resulting images were subset using the study area shapefile to bring out the satellite images of the area of interest (AOI). The AOI images were enhanced by filtering the imageries in Erdas Imagine, resampled and projected. The images were enhanced into natural colour composite to improve the visual interpretation. All the images were projected to Universal Transverse Mercator projection of WGS84 coordinate system, zone 31N.

Table 1 Satellite image characteristics

SN	Image Type	Path/Row	Acquisition Date	Resolution
1	Landsat 8 OLI/TIRS	191/54	24/12/2015	30 m
		191/55	24/12/2015	
		190/54	17/12/2015	
		190/55	17/12/2015	
2	Landsat 7 ETM	191/54	06/02/2000	30 m
		191/55	06/02/2000	
		190/54	15/02/2000	
		190/55	15/02/2000	
3	Landsat 5 TM	191/54	18/12/1984	30 m
		191/55	18/12/1984	
		190/54	11/12/1984	
		190/55	11/12/1984	

The supervised classification method in Erdas Imagine 2014 was adopted, using the maximum likelihood algorithm. The coordinates of some identified features within the basin were recorded and used as training samples for supervised classification of the remotely sensed data. One hundred and forty distributed training sites depicting all the main land use/land cover classes were used in each of the Landsat image used for the classification. The training sites (signatures) of all images were developed by using the spectral characteristics of known to train the classification algorithm for the land use/land cover mapping of the basin, which represent various land use/land cover of interest. After classification, ground truthing was carried out to verified doubtful areas in the classified image. The classified LULC classes were corrected using the recode option in Erdas Imagine. The accuracy assessment was conducted using 250 points, based on ground truth data and visual interpretation of the images. The 250 points were randomly selected in preparing confusion matrix for accuracy assessment, which is a popularly accepted method in determining the accuracy of LULC classification (Foody 2002). The 1984 and 2000 Landsat imageries could not be checked against the ground truth data point to validate the interpretation made. Hence, Google Earth images for these two periods were adopted for references. Tilahun and Teferie 2015; and Tadele et al. 2017 adopted similar approach in their studies with reasonable results. The randomly generated points in the classified 1984 and 2000 images were imported into Google Earth images of 31/12/ 1984 and 31/12/2000, respectively to verify the accuracy of the classifications. Also, the randomly generated points in the classified 2015 image was imported into Google Earth image of 14/12/ 2015 to verify the accuracy of the classification

(Tilahun and Teferie, 2015; Tadele et al., 2017) and the generated confusion matrix derived from the image and the points collected during ground truthing was also used for the accuracy assessment (Ismail and Jusoff, 2008). Thereafter, the Kappa coefficient and overall accuracy were calculated to assess the mapping accuracy of the LULC classification.

Seven land use/land cover classes reported in various part of the study area by Akinyemi (2005), Meginstu and Salami (2007) and Gasu et al. (2016) that include bare surfaces, built up area, crops/shrubs, forest, rock outcrops, water bodies and wetland were adopted as the basis for classification in this study. The land use/land cover maps of the basin for the period 1984, 2000 and 2015 were developed and measured for each land use/land cover types. A post classification detection approach was adopted for the change detection analysis. The change information was conducted using a pixel-based comparison, this enable us to interpret the changes overtime more effectively using the “-from, -to” information. The classified image of the three period were compared using cross-tabulation which assisted us to determine both qualitatively and quantitatively aspects of the changes for the year 1984 to 2000 to 2015. The change matrix (Weng, 2001; Rawat and Kumar, 2015) was prepared using Erdas Imagine. Therefore, the quantitative areal data of the total LULC changes, gains and losses in each LULC classes between the three period of investigation were compiled.

Modules for Land Use Change Evaluation (MOLUSCE) plugin in QGIS was adopted in simulating the future LULC change in the basin. MOLUSCE is designed to

analyze, model and simulate land use/cover changes and predict the future direction of change by using spatial change variables that include elevation, slope, aspects, distance to roads, population, etc. In this study, to simulate the future change in the drainage basin, the LULC change explanatory variables or change driving factors that include population, elevation, aspect and slope of the study area were adopted. The resulting predicted land use/land cover should be used with caution because there are other factors that can drive change in the future besides the factors adopted in this study. The Digital Elevation Model (DEM) of the study area was obtained from Shuttle Radar Topography Mission (SRTM) of the National Aeronautics and Space Agency (NASA). Elevation, aspect and slope of the study area were processed from DEM using ArcGIS 10.4. Also, the 1991 population of the study area acquired from National Population Census in Nigeria was projected using the 3.0 growth rate to get the population of the study area as at 2015. All these variables are ranked between 0 and 1 using the fuzzy membership tool in ArcGIS 10.4. The change transition matrix for the predicted 2046 LULC change was also computed.

RESULTS AND DISCUSSION

Land use/land cover classification, 1984-2015

The results of the seven (7) classified LULC for the study area are presented in Table 2 and Figure 2. In the base year, forest area constituted the most extensive type of land use/land cover of Osun drainage basin. Accordingly, it

Table 2 Land use/land cover classification of Osun Drainage Basin, 1984-2015

Land use/land cover types		1984		2000		2015	
		Area (Km ²)	%	Area (Km ²)	%	Area (Km ²)	%
1	Bare surfaces	2040.95	20.56	2709.57	27.30	3087.31	31.10
2	Built Up Areas	317.64	3.20	459.18	4.63	1063.91	10.72
3	Crops/Shrubs	1646.14	16.58	4163.35	41.94	3114.86	31.38
4	Forest	5223.61	52.62	2059.21	20.75	2154.87	21.71
5	Rock Outcrops	493.05	4.97	342.35	3.45	420.09	4.23
6	Water Bodies	50.76	0.51	61.64	0.62	61.59	0.62
7	Wetland	154.07	1.55	130.93	1.32	23.59	0.24
Total		9926.22	100.0	9926.22	100.00	9926.22	100.00

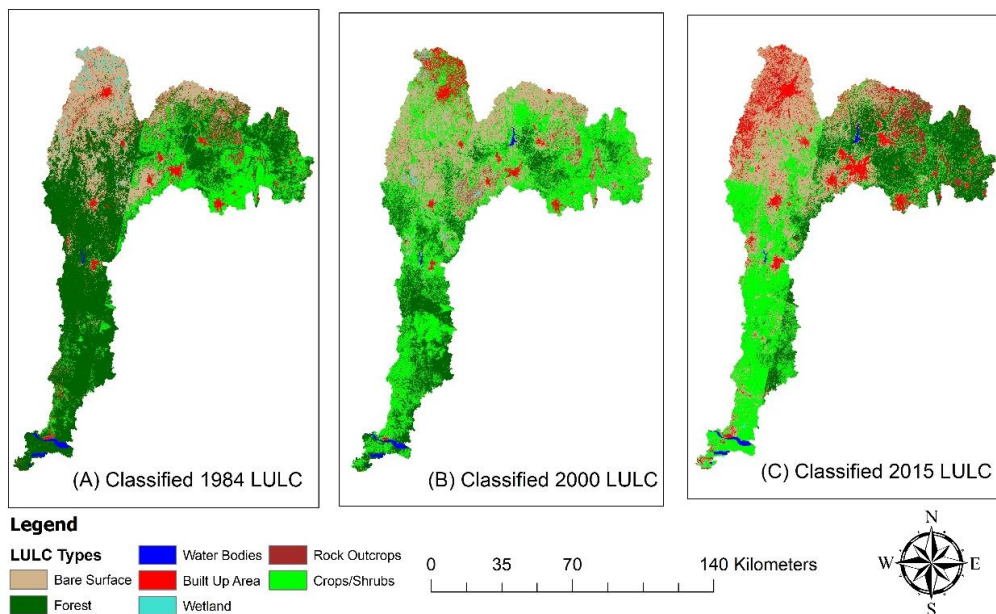


Fig. 2 The Classified Images of Osun Drainage Basin, 1984, 2000 and 2015

accounted for about 52.62% of the total drainage basin area in 1984, followed by bare surface and crops/shrubs, occupying 20.56% and 16.58% of the total drainage area, respectively (Table 2). About 0.51% of the study area was covered by the water bodies, which is the least of the seven (7) land use/land cover classified in 1984. In 2000, crops/shrubs, bare surfaces and forest covered 41.94%, 27.30% and 20.75%, respectively of the total basin area. Also, bare surface, crops/shrubs, forest covered 31.10%, 31.8% and 21.71%, respectively, while built up area accounted for 10.72% of Osun drainage area in 2015. For the LULC map of 1984, the Kappa coefficient and overall accuracy were found to be 0.71 and 0.80, respectively. The Kappa coefficient and overall accuracy were 0.80 and 0.85 for the year 2000 LULC map. Also, the Kappa coefficient and overall accuracy were found to be 0.79 and 0.82, respectively for the LULC map of 2015.

Land use/land cover change, 1984-2015

To explain the changes of one LULC class to another during the period of study, a change detection matrix was prepared and the results are presented in Table 3.

Land use/land cover change, 1984-2000

Between 1984 and 2000, bare surfaces, built up areas, crops/shrubs and water bodies gained a total land area of 668.62km², 141.54km², 2517.21km² and 10.88km², respectively. Crops/shrubs has a remarkable increase of 152.92%. It was also observed that built up area increased with about 44.56% between 1984 and 2000. This can be attributed to the increasing human population within the basin. Akinyemi (2005), Mengistu and Salami (2007) and Gasu et al. (2016) similarly reported increases in settlements/built up areas in their studies in the different parts of the basin. This confirms the fact that there is an increasing trend in the size of built up areas in the Osun drainage basin. The area covered by bare surfaces, built up areas, crops/shrubs and water bodies expanded at an annual average rate of 1.93%, 2.62%,9.00% and 1.26%, respectively between 1984 and 2000.

In the same period, forest, rock outcrops and wetland lost a total land area of 3164.40km², 150.70km² and 23.15km², respectively. The forest area decreased rapidly

with a total loss of 60.58% of its initial areal coverage. The sharp decrease in the size of forest between 1984 and 2000, is due to anthropogenic activities. Similar results were observed in some parts of the basin between 1986 and 2002 (Akinyemi, 2005; Mengistu and Salami, 2007). The forest area, rock outcrops and wetland receded at an annual rate of 3.56%, 1.80% and 0.88%, respectively between 1984 and 2000.

Land use/land cover change, 2000-2015

Built-up areas increased significantly during this period. It indeed increased by 131.70% from its original size of 459.18 km² in 2000 to 1064.91km² in 2015 (Table 3). This gives an average annual growth rate of 8.23%. A change largely due to increasing population and urbanization. As a matter of fact, the population of the basin that was put at 4,281,000 in 1980 by OORBDA (1982) was estimated to be 12,046,145 in 2015 by Ashaolu (2018). The increasing built-up areas can severely change the water balance of the study area, influence the rate of recharge and the microclimate of the area (Lerner et al., 1990; Jyrkama and Sykes, 2006). Also, the amount of direct groundwater recharge resulting from rainfall may reduce as a result of the increase in impervious surfaces from built up areas, while surface runoff will increase significantly (Rose and Peters, 2001). Expectedly, crops/shrubs, water bodies and wetland receded at an annual rate of 1.57%, 0.08% and 5.12%, respectively. For example, crops/shrubs lost an area of 1048.50 km², which is about 58% of its basin coverage in 2000. The study of Akinyemi (2005) in a small section of the drainage basin, while agreeing with this finding continues up until 2015.

Land use/land cover change, 1984-2015

The greatest percentage change for the 32-year-period was recorded on built-up area with about 235% increase at an average annual rate of 7.34% (Table 3). Built-up area increased significantly from 317.64 km² in 1984 to 1063.91km² in 2015. The increasing areal extent of the built-up areas confirmed the results of early studies (Akinyemi, 2005; Mengistu and Salami, 2007; Gasu et al., 2016) in some parts of the study area. Also, crops/shrubs gained about 89.22% with an average annual rate of 2.79%. Crops/shrubs increased by an area of 1468.22km², from

Table 3 Area and amount of change in land use/land cover categories in Osun Drainage Basin, 1984-2015.

Note: The signs + and - indicate increase and decrease, respectively

Land use/land cover types	1984-2000		Average rate of change (1984-2000)		2000-2015		Average rate of change (2000-2015)		1984-2015		Average rate of change (1984-2015)	
	Area (Km ²)	%	Area (Km ²)	%	Area (Km ²)	%	Area (Km ²)	%	Area (Km ²)	%	Area (Km ²)	%
1 Bare surfaces	668.62	32.76	39.33	1.93	377.74	13.94	23.61	0.87	1046.36	51.27	32.70	1.60
2 Built up areas	141.54	44.56	8.33	2.62	604.73	131.70	37.80	8.23	746.27	234.94	23.32	7.34
3 Crops/Shrubs	2517.21	152.92	148.07	9.00	-1048.50	-25.18	-65.53	-1.57	1468.72	89.22	45.90	2.79
4 Forest	-3164.40	-60.58	-186.14	-3.56	95.66	4.65	5.98	0.29	-3068.70	-58.75	-95.90	-1.84
5 Rock outcrops	-150.70	-30.57	-8.86	-1.80	77.74	22.71	4.86	1.42	-72.96	-14.80	-2.28	-0.46
6 Water bodies	10.88	21.44	0.64	1.26	-0.05	-0.07	0.00	0.00	10.84	21.35	0.34	0.67
7 Wetland	-23.15	-15.02	-1.36	-0.88	-107.34	-81.98	-6.71	-5.12	-130.48	-84.69	-4.08	-2.65

1646.16km² in 1984 to 3114.86km² in 2015. The increase recorded in the percentage area of crops/shrubs conform with the work of Salami et al. (1999), which reported that natural vegetation has largely been replaced by perennial and annual crops in many parts of the basin. The changes in land use/land cover during the 32 years, especially increase in built up and crops/shrubs can be attributed to population growth and settlement expansion, these scenarios had culminated into conversion of natural vegetation to farmland. Other human activities such as fuel wood extraction, sand mining, quarrying and gold mining etc. have all contributed to land use changes.

The most notable decrease in LULC classes in the Osun drainage basin was observed in the forest area and wetland. Forest decreased from a total land area of 5223.61km² (52.62%) in 1984 to 2154.87 km² (21.71%) in 2015. This is similar to the study of Hammad et al. (2018) in the southern Syria coastal basin where forest area decreased from about 64% in 1987 to about 38% in 2017. The forest area receded at an annual average rate of 1.84% during the period under investigation. This can be attributed to the years of human occupation and interference with the tropical vegetation of the drainage basin. The long history of agricultural practices and increasing population density in the area would have resulted into substantial modification of the natural vegetation. Wetland declined from a total land area of 154.07 km² in 1984 to 23.59 km² in 2015. Wetland area receded at an annual average rate of 4.08 km² during this period. This is attributable to wetland being converted to built-up area as there is need for accommodation for the teeming population in the basin. Figure 3 shows the percentage change in LULC in Osun Drainage Basin between 1984 and 2015. This shows the areal extent's increase or decrease by each LULC in percentages.

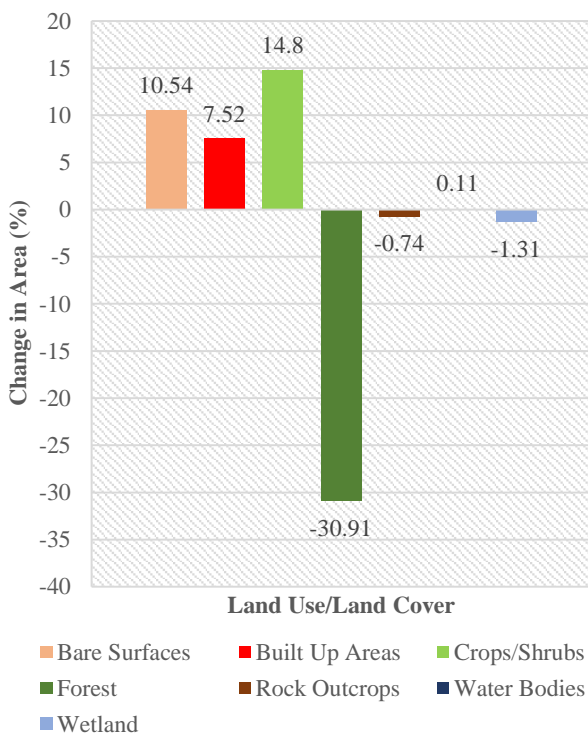


Fig. 3 Percentage change in land use/land cover in Osun Drainage Basin, 1984-2015

The socio-economic characteristics of the people in the study area has significantly influenced the changes in LULC observed. Most communities in Osun drainage basin earn their living through farming, logging and fuel wood production. The issue of climate change is another major cause of the disappearing natural vegetation in addition to the prevailing human activities. The Sudano-sahelian zone has been reported to be advancing southward of latitude 10°N resulting in loss of forest species and arable lands. All these are responsible for the rapidly changing land use and land cover in the Osun drainage basin (Fasona and Omojola, 2005; Mengistu and Salami, 2007). The implications of the changing LULC include increasing incidences of soil erosion, increasing reservoir sedimentation, soil degradation and unfavourable changes in the hydrological regime. Groundwater recharge is influenced by plant cover and land use practices. Hence, the type and nature of land cover can have a significant influence on infiltration, and on groundwater recharge (Jyrkama and Sykes, 2006). Altering the natural land surface as observed in this study will significantly alter the groundwater recharge (Lerner et al. 1990; Lerner 2002) of the drainage basin.

The results of the change detection transition matrix between 1984 and 2015 (Table 4) revealed that:

- about 25% of the area that are bare surface in 1984 has been converted into built-up area, 4.55% are crops/shrubs, 5.06% are rock outcrops, while 65.43% remained unchanged;
- about 32% of forest area in 1984 remained unchanged, while it lost 43.70% and 21.68% to crops/shrubs and bare surfaces, respectively;
- rock outcrops lost 35.12% to bare surfaces, 13.46% to built-up areas and 12.40% of its areal extent to crops/shrubs;
- no significant conversion of water bodies to other LULC class, as it maintained 89.35% of its size; and
- about 66% of wetland was converted to bare surfaces.

The forest area, bare surface and crops/shrubs LULC classes were the most significant land cover transitions during the period of investigation. Hence, spatial analysis was performed on the three classes to evaluate the spatial texture of these changes during the periods 1984 to 2015 (Fig. 4).

Predicted future land use/land cover change in Osun Drainage Basin, 2046

Based on the rate of change between 1984 and 2015, the predicted LULC change revealed that by 2046, bare surface will increase slightly by 188.01 km² (Table 5). Thus, bare surface would have increased from 3087.31 km² in 2015 to 3275.32 km² in 2046. Built-up area would have increased steadily from 1063.91 km² in 2015 to 1658.85 km² by 2046. This is 55.92% increase. The simulated result shows that the increase in built-up area are closely associated with the existing built-up areas. This will be more pronounced in the northwestern part of the study area, especially in the Oyo State portion of the basin, in and around Ogbomosho. The growth that will be experienced in this area is attributable to population

Table 4 Land use/land cover change transition matrix in Osun Drainage Basin (1984-2015). Figures in the upper rows indicate areas of particular LULC type that remained unchanged (in bold) or converted to other LULC types in Km². Figures in italics in the lower rows indicate areas of particular LULC type that remained unchanged (in bold) or converted to other LULC types in percentage

Land use/land cover categories		Land use/land cover 2015 (Km ²)							Total area
		Bare surfaces	Built up areas	Crops/Shrubs	Forest	Rock outcrops	Water bodies	Wetland	
Land use/land cover 1984 (Km ²)	Bare surfaces	1333.54 <i>65.43</i>	493.53 <i>24.8</i>	92.93 <i>4.55</i>	15.31 <i>0.75</i>	103.37 <i>5.06</i>	0.80 <i>0.04</i>	1.48 <i>0.07</i>	2040.95 <i>100</i>
	Built up areas	3.50 <i>1.10</i>	309.96 <i>97.58</i>	3.25 <i>1.02</i>	0.00 <i>0.00</i>	0.70 <i>0.22</i>	0.06 <i>0.02</i>	0.17 <i>0.05</i>	317.64 <i>100</i>
	Crops/Shrubs	343.56 <i>20.87</i>	108.61 <i>6.60</i>	667.99 <i>40.58</i>	437.51 <i>26.58</i>	81.89 <i>4.97</i>	6.42 <i>0.39</i>	0.16 <i>0.01</i>	1646.14 <i>100</i>
	Forest	1132.32 <i>21.68</i>	41.22 <i>0.79</i>	2282.96 <i>43.70</i>	1649.40 <i>31.58</i>	91.07 <i>1.74</i>	7.17 <i>0.14</i>	19.48 <i>0.37</i>	5223.61 <i>100</i>
	Rock outcrops	173.21 <i>35.13</i>	66.36 <i>13.46</i>	61.14 <i>12.40</i>	51.45 <i>10.44</i>	139.67 <i>28.33</i>	0.43 <i>0.09</i>	0.78 <i>0.16</i>	493.05 <i>100</i>
	Water bodies	0.06 <i>0.12</i>	0.56 <i>1.10</i>	3.84 <i>7.56</i>	0.03 <i>0.07</i>	0.12 <i>0.23</i>	45.35 <i>89.35</i>	0.80 <i>1.57</i>	50.76 <i>100</i>
	Wetland	101.12 <i>65.63</i>	43.68 <i>28.35</i>	2.76 <i>1.79</i>	1.16 <i>0.75</i>	3.28 <i>2.13</i>	1.35 <i>0.88</i>	0.72 <i>0.47</i>	154.07 <i>100</i>
	Total Area	3087.31	1063.91	3114.86	2154.87	420.09	61.59	23.59	9926.22

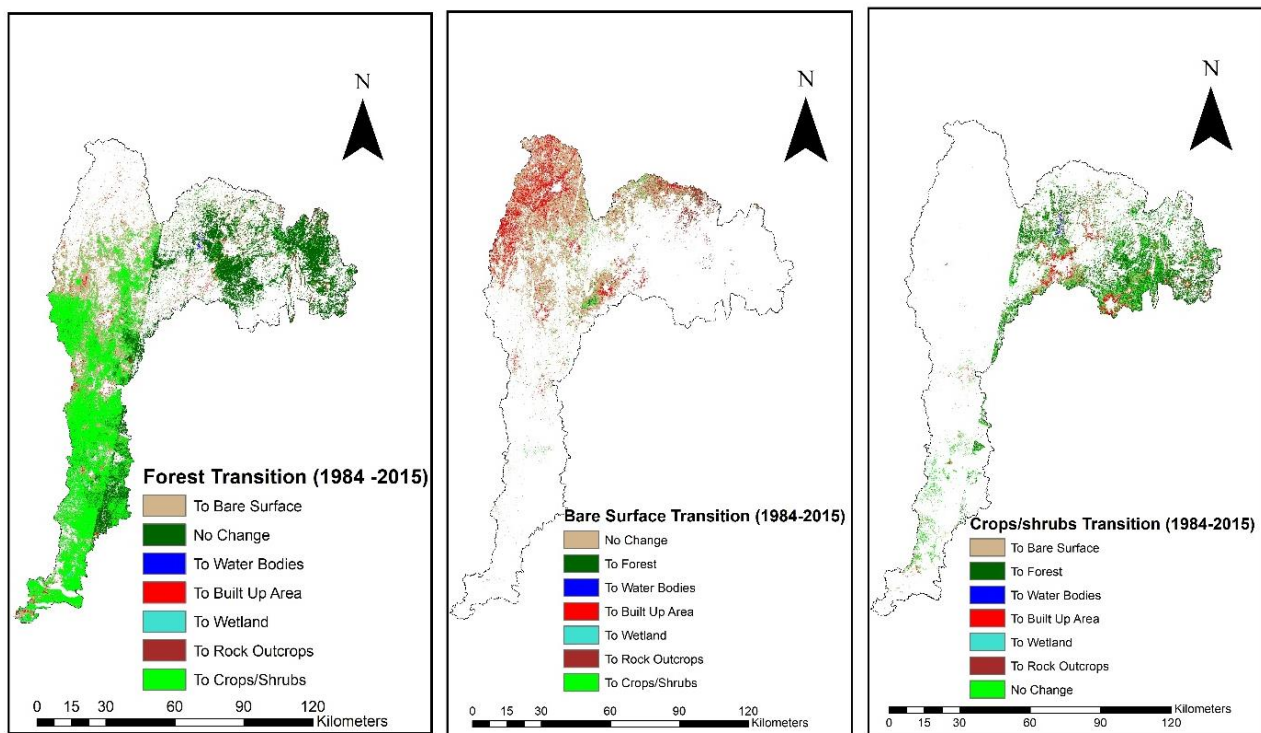


Fig. 4 Transition of forest, bare surface and crops/shrubs to other land classes (1984-2015)

increase, that will lead to the expansion of built-up areas. Also, crops/shrubs LULC class will increase slightly from 3114.86 km² in 2015 to 3311.11 km² by 2046, which is an increase of 6.30%. This suggests that farming activities in the basin will increase only slightly. There may be further increase, if the effort of the Federal Government of Nigeria to diversify the economy is vigorously pursued.

The future LULC change revealed that between 2015 and 2046, the forest area will continue to decrease. As much as 897.69 km² of forest land may be lost to other

uses between this period. Thus, it is expected that forest area will decrease from 2154.86 km² in 2015 to 1257.18 km² by 2046. The 42% reduction in forest area, is worrisome because it reflects the unrelenting activities of wood loggers in the study area. Continuous deforestation of the forest area will certainly have significant impacts on the water budget of the study area, especially groundwater recharge. Based on this study, water bodies LULC will decrease by 2.70%. Wetland which is one of the important groundwater recharge mechanisms in a

Table 5 Predicted land use/land cover change between 2015 and 2046. The signs + and - indicate increase and decrease, respectively

Land use/land cover types	2015		2046		2015-2046		Average rate of change (2015-2046)	
	Area (Km ²)	%	Area (Km ²)	%	Area (Km ²)	%	Area (Km ²)	%
1 Bare surface	3087.31	31.1	3275.32	33.00	188.01	6.09	5.88	0.19
2 Built up areas	1063.91	10.72	1658.85	16.71	594.94	55.92	18.59	1.75
3 Crops/Shrubs	3114.86	31.38	3311.11	33.36	196.25	6.30	6.13	0.20
4 Forest	2154.87	21.71	1257.18	12.67	-897.69	-41.66	-28.05	-1.30
5 Rock outcrops	420.09	4.23	359.79	3.62	-60.30	-14.35	-1.88	-0.45
6 Water bodies	61.59	0.62	59.93	0.60	-1.66	-2.70	-0.05	-0.08
7 Wetland	23.59	0.24	4.04	0.04	-19.55	-82.87	-0.61	-2.59
<i>Total</i>	9926.22	100	9926.22	100.00				

drainage basin would have decreased in size from 23.59 km² in 2015 to mere 4 km² by 2046. The predicted 2046, land use and land cover change in Osun drainage basin, Nigeria is presented in Figure 5.

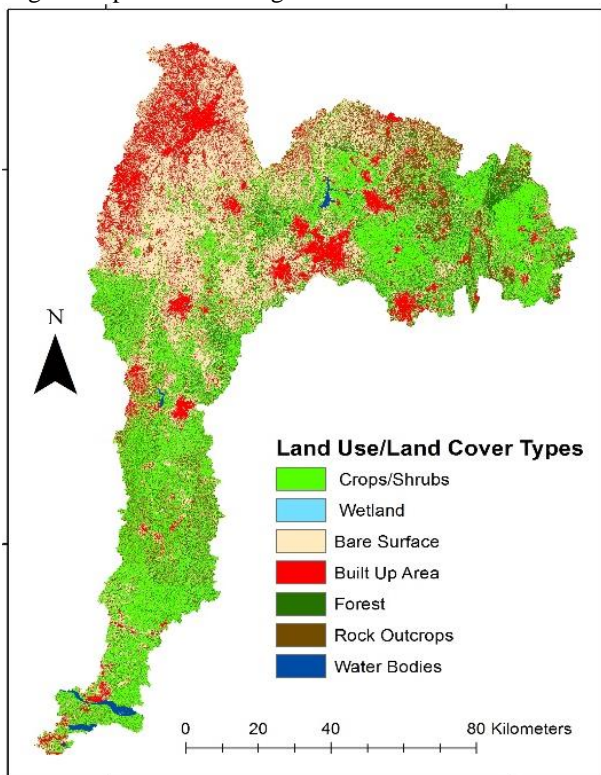


Fig. 5 The predicted, land use and land cover for 2046 in Osun drainage basin, Nigeria

In summary, the change detection transition matrix between 2015 and 2046 (Table 6) indicates that:

- about 16% of the bare surface in 2015 will be converted into built-up area by 2046;
- there will be no significant decrease in built-up areas, rather it will increase from 1063.91 km² to 1658.85 km²;
- about 34% of wetland would have been converted to built-up area;
- significant areal extent of about 1349 km² of forest will be converted to crops/shrubs; and
- water bodies will remain about 96.61% of its size in 2015 by 2046.

CONCLUSION

In conclusion, land use/land cover change for the period 1984-2015 were examined based on the data generated from satellite imageries. LULC change transition matrix was computed with a view to determining the percentage change of one land class to another during the period of study. Also, the future LULC change was simulated for the year 2046, to understand the level and direction of change that might be experienced in the future in Osun drainage basin. The LULC change in the basin revealed that built-up area increased by about 235% between 1984 to 2015. Forest area declined by 59% and crops/shrubs increased with about 89%, during the same period. The rate of change of LULC in the Osun drainage basin may not be unconnected to population increase and settlement expansion with their accompanying anthropogenic activities which include fuel wood extraction, wood logging, and sand mining, etc. All these anthropogenic activities resulted into the loss of the original rainforest in the basin. The land use/land cover change scenario in Osun drainage basin will influence the water budget and hydrology of the study area, with the probability of changing the rate of interception, evapotranspiration, runoff and groundwater recharge in the basin. In fact, the predicted future LULC change suggests that only about 12% of the basin will remain under forest cover by the year 2046. The results have underscored the increasing human occupation and the high rates of conversion of the natural vegetation into other land use classes. The rate at which forest cover declined in Osun drainage basin unabated is a pointer to the fact that even after the United Nations Millennium Development Goal (MDG) terminated in 2015, one of her goals to ensure environmental sustainability by reversing the loss of forests in all regions of the world was not met in Sub-Saharan Africa and Nigeria in particular. It is paramount that the rate of deforestation and unregulated land use in the larger part of the basin be discouraged for a sustainable drainage ecosystem. In addition, the planting of the lost native trees should be encouraged for the sustainability of the basin's ecosystem.

Table 6 Land Use/Cover Change Transition Matrix in Osun Drainage Basin (2015-2046) Figures in the upper rows indicate areas of particular LULC type that remained unchanged (in bold) or lost to other LULC types in Km². Figures in italics in the lower rows indicate areas of particular LULC type that remained unchanged (in bold) or lost to other LULC types in percentage

Land use/cover categories		Predicted land use/land cover 2046 (Km ²)							Total Area
		Bare surfaces	Built up areas	Crops/Shrubs	Forest	Rock outcrops	Water bodies	Wetland	
Land use/land cover 2015 (km ²)	Bare surfaces	2493.64 <i>80.77</i>	495.55 <i>16.05</i>	24.56 <i>0.80</i>	22.90 <i>0.74</i>	50.49 <i>1.64</i>	0.10 <i>0.00</i>	0.06 <i>0.00</i>	3087.31 <i>100</i>
	Built up areas	77.26 <i>7.26</i>	968.01 <i>90.99</i>	12.00 <i>1.13</i>	5.22 <i>0.49</i>	1.20 <i>0.11</i>	0.16 <i>0.02</i>	0.06 <i>0.01</i>	1063.91 <i>100</i>
	Crops/Shrubs	352.85 <i>11.33</i>	107.96 <i>3.47</i>	1911.06 <i>61.35</i>	661.13 <i>21.23</i>	81.57 <i>2.62</i>	0.00 <i>0.00</i>	0.30 <i>0.01</i>	3114.86 <i>100</i>
	Forest	297.69 <i>9.64</i>	24.19 <i>1.12</i>	1348.98 <i>62.60</i>	544.63 <i>25.27</i>	27.99 <i>1.30</i>	0.03 <i>0.00</i>	1.37 <i>0.06</i>	2154.87 <i>100</i>
	Rock outcrops	130.31 <i>31.02</i>	55.02 <i>13.10</i>	13.49 <i>3.21</i>	22.80 <i>5.43</i>	198.34 <i>47.21</i>	0.12 <i>0.03</i>	0.00 <i>0.00</i>	420.09 <i>100</i>
	Water bodies	0.75 <i>1.22</i>	0.16 <i>0.26</i>	0.74 <i>1.21</i>	0.09 <i>0.15</i>	0.07 <i>0.11</i>	45.35 <i>96.61</i>	0.80 <i>0.45</i>	61.59 <i>100</i>
	Wetland	12.82 <i>54.35</i>	7.95 <i>33.69</i>	0.28 <i>1.20</i>	0.41 <i>1.74</i>	0.14 <i>0.60</i>	0.01 <i>0.03</i>	1.98 <i>8.39</i>	23.59 <i>100</i>
	Total Area	3275.32	1658.85	3311.11	1257.18	359.79	59.93	4.04	9926.22

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CLASSIFICATION OF WATER QUALITY OF BANAT WATERCOURSES IN SERBIA FOR THE NEEDS OF IRRIGATION

Milica Ilić, Milica Vranešević*, Atila Bezdan, Boško Blagojević

University of Novi Sad, Faculty of Agriculture, Department of Water Management, Trg Dositeja Obradovića 8, 21000 Novi Sad, Serbia

*Corresponding author, e-mail: milicaraj@polj.uns.ac.rs

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Abstract

The composition of water used for irrigation has a significant impact on the production characteristics of the land, yield and irrigation equipment, and therefore its analysis, or assessment of the usability of irrigation water is very important. In this paper, the potential impact of the waters of the Banat watercourses of Moravica, Karaš and Nera is assessed on the basis of monthly water samples from the measuring stations of Vatin, Dobričevo and Kusić, for the period of April-September from the year 2007 to 2017. The assessment was carried out using the classification of irrigation water: FAO, USLL and water categorization according to Negebauer, and the Serbian Water Quality Index (SWQI). For the needs of these classifications, a total of 20 water parameters were analyzed: quality, physical, chemical and biological parameters. According to all the classifications, the analyzed watercourses can be a good source of water for irrigation in terms of its quality, but with control and appropriate measures, in particular, the presence of bicarbonate, but also the ratio of Na^+ to Ca^{2+} and Mg^{2+} .

Keywords: Water quality, WQI, Irrigation, Vojvodina

INTRODUCTION

The frequent occurrence of extreme drought periods is a major constraint on agricultural production that needs to meet the demands of increasing food demand. Production under the irrigation systems can significantly increase yields, as indicated by the fact that about 40-50% of plant production in the world is realized on about 16% of arable irrigated area (Savić et al., 2013). The result of irrigation is in the function of many factors, both natural and anthropogenic, and in terms of water, it is necessary to pay attention to the amount that is being applied, but also to pay attention to its quality. It is known that the composition of water used for irrigation has a major impact on soil characteristics, on yield and quality of cultivated plants, and on irrigation equipment (Ayers and Westcott, 1985; Bortolini et al., 2018; Bauder et al., 2011; Fipps, 2003). Increasing total salts, individual ions and their adverse relationship increases the risk of unwanted consequences. The assessment of the usability of water should be done according to parameters that have a direct impact on the soil in terms of its productivity and in accordance with its characteristics. The most common problems that occur with the use of inadequate irrigation water according to Ayers and Westcott (1985) can be divided into four groups: salinization, permeability, toxicity and miscellaneous problems. Each of the problems can be expressed individually or in combination with other problems. The problem of salinity was observed at about 20-30 million ha of about 260 million hectares of irrigated land in the world (Tanji and Kielen, 2002). On some of the irrigated areas in Vojvodina, heavily mineralized water has already led to the

emergence of secondary salinization of soil. The problem of salinization is considered in terms of degradation of soil and accessibility of water to plants. Stress caused by lack of water is similar to stress caused by excess of salt in the soil (Munns, 2002). Salinization has impact on growth of plants (Ghoulam et al., 2002; Munns, 2002), on their water regime, (Ayers and Westcott, 1976), mineral intake (Grattan and Grieve, 1999; Hassan et al., 1970;), the capacity of the photosynthetic apparatus decreases with increased saturation (Asharaf, 2001), etc. Water of inadequate quality can cause deterioration of soil structure and thus reduce infiltration. Reduced infiltration ability prevents plants from being supplied with the required amount of water. Two factors related to the quality of water for irrigation that most affect the degree of infiltration are the total amount of salt in water, as well as the ratio of individual cations, more precisely the ratio of sodium to calcium and magnesium (Ayers and Westcott, 1985). Some ions show toxic effects on plants by reducing their yield and quality, among which Cl^- , Na^+ and B are distinguished, and maximal allowed concentration depends on the plant species. Irrigation equipment can be damaged by the presence of certain elements, which primarily refers to congestion of the emitters, and this results in poor uniformity of watering, leading to unequal development of plants. Regarding the impact on the equipment of the irrigation system, suspended solids, bicarbonates, sulfides, manganese and iron are separated (Bortolini et al., 2018). In order to prevent adverse effects, water quality assessment should become a necessary measure in the production under irrigation systems (Joshi et al., 2009), whereby agronomic, ecological, technical and economic criteria can be applied. An analysis of water

quality parameters of three water courses in South Banat was carried in this paper out in order to be classified in certain classes and in accordance with them defined the possibility of use for irrigation in the spatial sense.

STUDY AREA

Vojvodina belongs to the southern parts of the Pannonian Plain and is located between 44° 38' and 46° 11' northern geographic width, that is of 18° 49' and 21° 00' of eastern geographic length with an area of 21 506 km². It represents one of the most productive areas in the world for agricultural production. However, agricultural production is not at the level at which it can be, and one of the main reasons is the lack of moisture during the vegetation period, which is due to high temperatures and insufficient precipitation (Rajić, 2003). Exceptional natural benefits, i.e. the plain of highly productive agricultural land and a relatively sufficient amount of surface water provide the possibility of intensive development of production under irrigation conditions. The Government of the Republic of Serbia plans to increase the area under the irrigation systems and therefore it is necessary to consider all the factors of convenience for implementation or deficiencies in order to make a decision on potential irrigated areas. On existing systems, most water is obtained from surface flows, which indicates the importance of their quality assessment for these purposes (Savić et al., 2013).

Watercourses Moravica, Karas and Nera are located in the South Banat District (eastern part of Vojvodina, Serbia) in settlements and the measuring stations with the same names: Vatin, Dobricevo, and Kusic. Out of the total area of the South Banat, the

agricultural area extends to around 80%, more precisely, 341.268 ha. Figure 1 shows the location of the measuring points from which the analyzed samples were taken.

MATERIALS AND METHODS

The quality of water of Moravica (15+000), Karaš (14+000) and Nera (21+000) was assessed upon monthly samplings obtained in the period of April-September (vegetation period) from 2007 to 2017. Data on physical, chemical and biological parameters of sample quality were taken from the Hydrological Yearbook of water quality of the Republic Hydrometeorological Institute of Serbia (HIDMET, 2007-2010) and from the Agency for the protection of the environment (SEPA, 2011-2017). A detailed analysis of the parameters required for the application of the three water classification classes for irrigation has been carried out: FAO classification (Ayers and Westcott, 1985), US Salinity Laboratory classification (USSL) (Richards, 1954) and categorization of water according to Nejgebauer, which is adapted to the natural conditions of Vojvodina (Belić et al., 2011). The basis of these classifications is the analysis of potential problems of salinization and alkalization, i.e. analysis of the concentration of total salt in water and of sodium, or its relation to divalent cations (Ca²⁺ and Mg²⁺), and FAO classification provides more detailed analyses. In addition to the above classifications, water quality is assessed by the index method Serbian Water Quality Index (SWQI) (www.sepa.gov.rs) which could be characterized as the general assessment of water quality. In addition to chemical parameters, this method also analyzes the biological and physical parameters of water quality. The analyzed quality parameters and their values are given in Table 1.

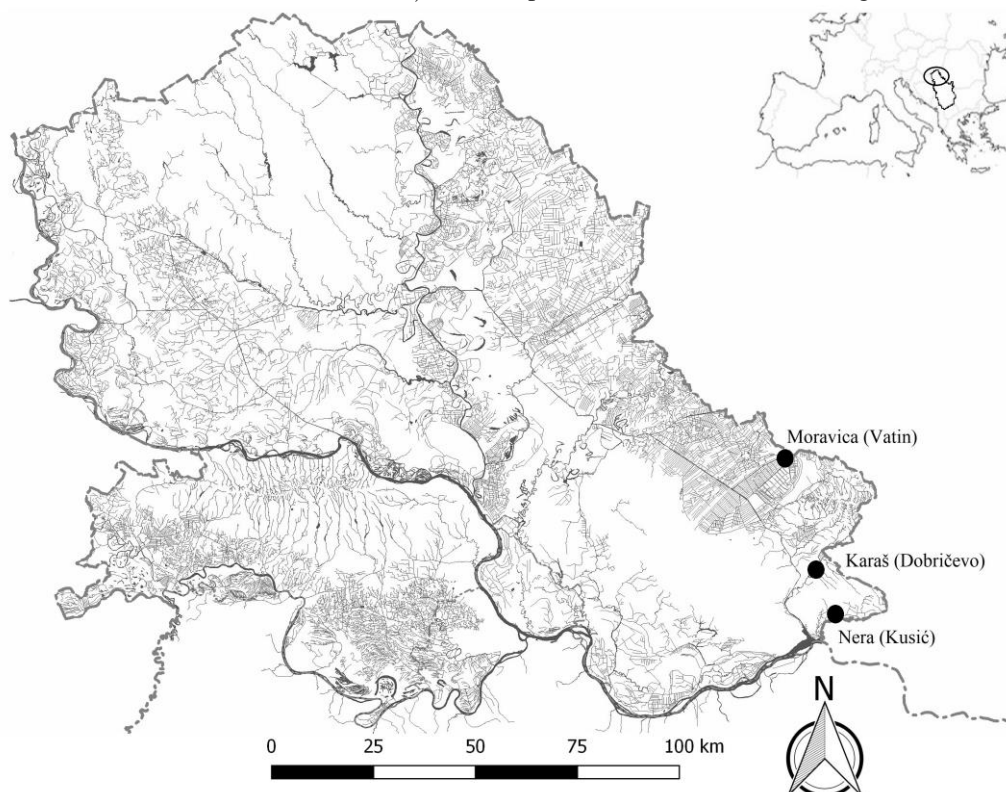


Fig. 1 Location of measuring point on watercourse Moravica, Karaš and Nera

Table 1 Minimum, maximum, means and standard deviations (SD) of analyzed parameters in period April-September, 2007-2017

Parameter	Moravica				Karaš				Nera			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Ca ²⁺ (mg/l)	33.0	89.0	64.7	15.3	2.6	109.0	70.6	23.4	37.0	67.4	51.3	6.4
Mg ²⁺ (mg/l)	12.0	57.0	33.3	10.7	3.0	122.0	85.36	10.2	2.0	10.0	5.2	1.6
Na ⁺ (mg/l)	8.4	80.5	42.7	15.2	4.5	29.0	14.9	5.3	0.7	9.0	5.5	1.7
K ⁺ (mg/l)	0.9	10.6	4.6	2.1	1.2	7.5	6.4	2.1	0.5	4.6	1.7	0.7
SO ₄ ²⁻ (mg/l)	19.0	73.0	40.5	10.5	20.0	56.0	34.6	8.5	13.0	290.0	36.4	42.3
Cl ⁻ (mg/l)	11.4	73.0	27.7	11.5	6.2	24.7	11.6	3.2	3.6	19.0	6.1	2.5
NO ₃ -N (mg/l)	0.05	9.30	0.51	1.35	0.11	3.78	0.92	0.60	0.02	2.71	0.49	0.38
CO ₃ ²⁻ (mg/l)	0.0	31.1	3.5	7.8	0.0	19.0	2.5	5.3	0.0	27.6	2.5	4.6
HCO ₃ ⁻ (mg/l)	152.0	534.0	385.7	99.9	152.0	354.0	254.2	33.82	105.0	362.0	164.0	34.5
EC (□S/cm)	281	913	655.4	170	317	668	466.9	60.4	224	364	292.3	31.4
TDS (mg/l)	207	560	431.2	92.2	206	458	290.4	39.7	138	226	181.3	17.4
pH value	6.4	8.7	7.9	0.4	7.7	8.4	8.1	0.2	7.7	8.8	8.2	0.2
Temperature (°C)	13.7	28.6	21.1	4.1	10.2	36.0	19.5	4.6	8.5	28.0	18.2	4.9
Oxygen saturation (%)	15	184	75.7	39.1	71	145	95.4	11.2	72	128	99.5	10.0
BOD ₅ (O ₂ mg/l)	1.0	13.6	3.4	2.4	1.0	5.5	2.2	0.9	0.8	3.5	1.7	0.6
NH ₄ -N (mg/l)	<0.02	0.65	0.08	0.11	<0.02	0.81	0.09	0.11	<0.02	0.25	0.05	0.04
Total oxides of nitrogen (mg/l)	0.06	9.37	0.53	1.36	0.13	3.84	0.94	0.60	0.03	2.71	0.50	0.38
Orthophosphates (mg/l)	0.02	0.85	0.23	0.17	0.01	0.81	0.09	0.11	0.02	0.85	0.23	0.17
Suspended solids (mg/l)	2	213	30.7	38.3	2	208	37.8	46.4	1	205	25.8	40.1
SAR	0.30	2.38	1.06	0.35	0.14	0.78	0.42	0.13	0.03	0.37	0.2	0.06

RESULTS AND DISCUSSION

Moravica

According to the FAO classification criteria, Moravica water qualities in terms of salinization alternately changed from first class, which has no limitations to moderate need for limitation (Class II). According to the influence of water on infiltration, the quality condition is similar. Concentrations of Na⁺ and of Cl⁻ are within the limits in which they do not exhibit toxic effects on plants. Special attention should be paid to the possible effects of bicarbonate whose concentration was within the class of moderate use restriction (II classes) with occasional occurrences of the need for serious limitations (III classes). The percentage of Moravica watercourse classes during the observed period according to the FAO classification is given in Table 2.

Table 2 Percentual representation of certain Moravica water classes according to the FAO classification, vegetation period 2007-2017

Potential problems	Class	%
Salinity	I	54.9
	II	45.1
Infiltration	I	52.9
	II	47.1
Toxicity of Na	I	98.0
	II	2.0
Toxicity of Cl ⁻	I	100
Effects of NO ₃ ⁻	I	98.0
	II	2.0
Effects of HCO ₃ ⁻	II	94.1
	III	5.9

USSL classification, based on the value of electrical conductivity and the Sodium Adsorption Ratio, water samples Moravica were classified mainly in the C2-S1 class, more precisely about 60% of the samples, and about 40% in the C3-S1 class (Fig. 2). The ratio of sodium to calcium and magnesium is favorable and there is no danger in this respect. In terms of total salt, Moravica water is characterized as "medium salty" and "salty" and therefore measures such as soil erosion, choice of cultures resistant to salt, and the inability to use this water on naturally poorly drained soils are necessary. The fact that benefits in favor of use is that class C3 is observed most often in months when irrigation is only applied intermittently (April, May), but due to occasional occurrence and in the irrigation season, regular controls and measures are in line with quality.

According to Nejgebauer's classification, the quality of water is "good" in most of the observed period, or more precisely, almost 80% of the samples. In addition, the samples were of "excellent quality", and only one sample is classed as unfit for irrigation, which may be the result of a local pollution just before water sampling (Fig. 3).

Water quality of Moravica, according to Serbian Water Quality methodology can be defined as "bad" with approximately 60% of samples which belonged to that class (Fig. 4). However, according to this method, such quality is useable for irrigation. However, the minimum quality index was 41, which is close to the limit of inapplicability (38). The remaining samples were "good", "very good" and in very few cases of "excellent" quality. Table 3 shows the descriptive statistics of the Moravica water quality index for the observed period, and the average monthly values and descriptive water quality indicator are shown in Table 4 where it can be seen that the average values of the index corresponding to the "poor" water quality are closer to the lower border of quality "good" water.

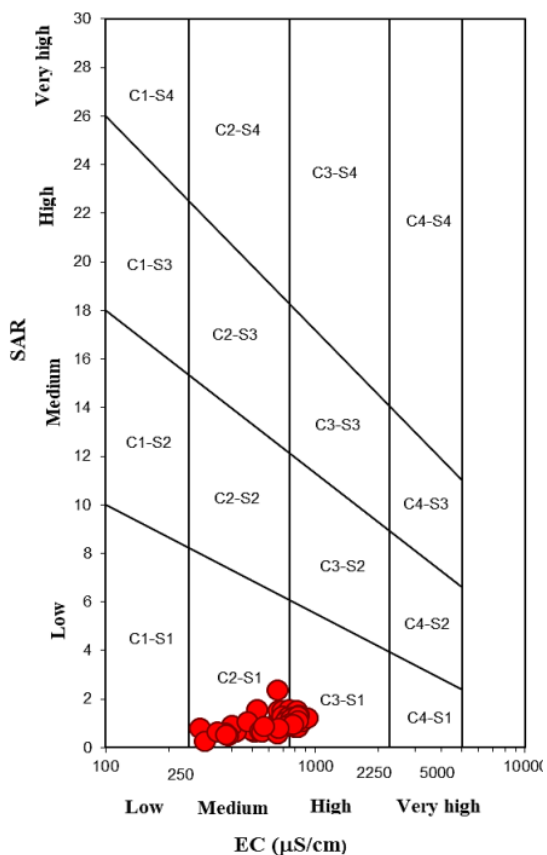


Fig. 2 Moravica water classes according to USSSL classification, vegetation period 2007-2017

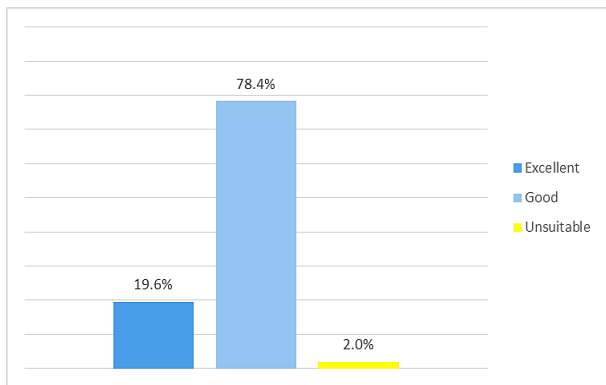


Fig. 3 Percentual representation of certain Moravica water classes according to Nejebauer classification, vegetation period 2007-2017

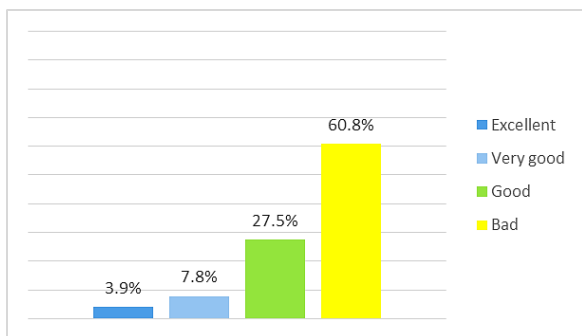


Fig. 4 Percentile representation of certain Moravica water classes according to SWQI methodology, vegetation period 2007-2017

Table 3 Minimum, maximum, mean and standard deviations (SD) of SWQI, vegetation period April-September, 2007-2017

	SWQI
Minimum	41
Maximum	91
Mean	68
SD	11

Table 4 Average monthly values of Index of Moravica water quality, vegetation period 2007-2017

April	May	June	July	August	September
81	71	63	62	61	68
Good	Bad	Bad	Bad	Bad	Bad

Karaš

The water quality of Karaš varied only in one class according to each FAO classification criteria (Table 5). According to the influence of water on permeability all samples are classified in the class of moderate usage limitation (II classes), as well as due to the diverse effects of bicarbonate. According to other criteria, water is of the highest quality for irrigation purposes.

USSL classification classifies water in class C2-S1, i.e. "Salty" water without a significant risk of the effect of adsorbing harmful sodium in terms of alkalization. Figure 5 shows that the EC values varied from lower to upper limit of the class, while all SAR values are closer to the lower limit value of the class.

Table 5 Percentile representation of individual water classes of Karaš according to the FAO classification, vegetation period 2007-2017

Potential problems	Class	%
Salinity	I	100
Infiltration	II	100
Toxicity of Na	I	100
Toxicity of Cl ⁻	I	100
Effect of NO ₃ ⁻	I	100
Effect of HCO ₃ ⁻	II	100

Mild criteria have a classification according to Nejebauer, and it places this water in the first class, i.e. water of "excellent" quality for irrigation, which shows that there are no risks of harmful effects of salt in quantitative or qualitative terms.

Figure 6 shows the results of the SWQI method. This classification shows a higher variability of water quality, but it also takes into account other parameters, in addition to chemical, physical and biological. An equal number of samples, about 40% belong to "very good" and "good" water quality, while others are classified as "excellent" and "bad" quality.

On this watercourse, quality was not unsuitable for use during the analyzed period. The basic statistical indicators of the water quality index Karaš are shown in Table 6. Average monthly values of the index corresponded to "very good" and "good" quality (Table 7).

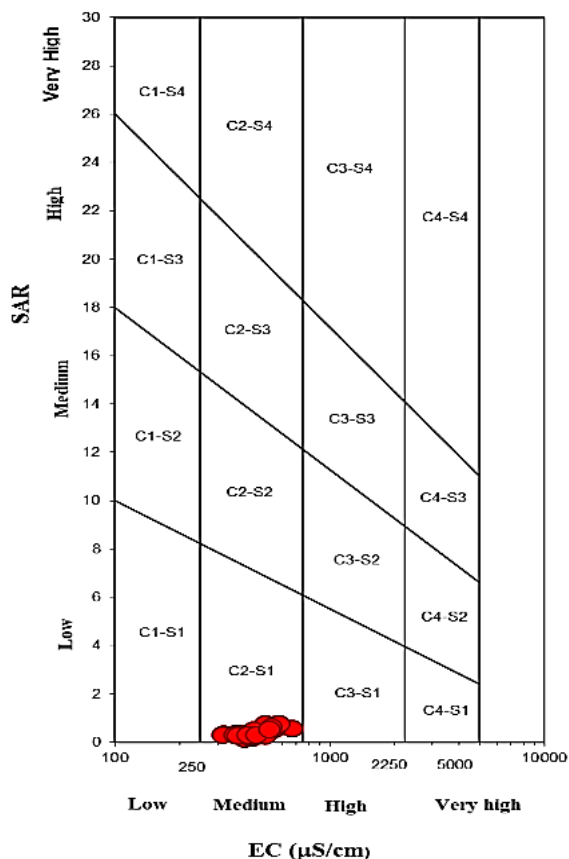


Fig. 5 Classes of water of Karaša according to USSL classification, vegetation period 2007-2017

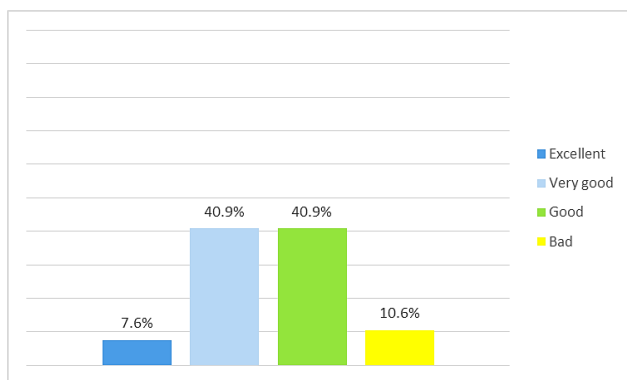


Fig. 6 Percentile representation of individual water classes of Karaša according to SWQI methodology, vegetation period 2007-2017

Table 6 Minimum, maximum, mean and standard deviations (SD) of SWQI, vegetation period April-September, 2007-2017

	SWQI
Minimum	63
Maximum	95
Mean	82
SD	7

Table 7 Average monthly values of the Quality index of water of Karaš, vegetation period 2007-2017

	April	May	June	July	August	September
Quality Index	87	84	76	78	80	86
Quality Class	Very good	Very good	Good	Good	Good	Very good

Nera

As well as on the Karas watercourse, Nera's water quality did not exhibit variability outside the class-defined by FAO criteria (Table 8). Problems related to soil infiltration are moderate, as well as problems that can be caused by elevated concentration of bicarbonate. In terms of total salt, i.e. accessibility of water to the plants, there are no problems, nor in terms of toxicity and the content of nitrates.

Figure 7 shows the results of Nera water quality according to the USSL classification where it can be observed that the EC and SAR values are relatively low and low variability. About 95% of the samples are categorized into C2-S1 and 5% in C1-S1. By classification by Nejšebauer, all water samples are classified in "excellent" quality (Fig. 8).

Table 8 Percentile representation of representation of certain Nera water classes according to the FAO classification, vegetation period 2007-2017

Potential problems	Class	%
Salinity	I	100
Infiltration	II	100
Toxicity of Na	I	100
Toxicity of Cl ⁻	I	100
Effects of NO ₃ ⁻	I	100
Effects of HCO ₃ ⁻	II	100

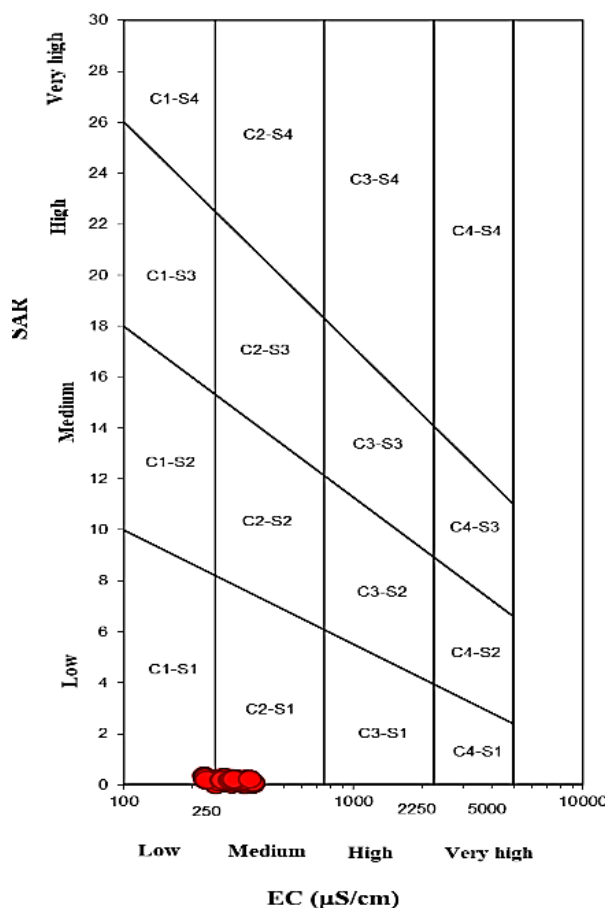


Fig. 7 Nera water classes according to USSL classification, vegetation period 2007-2017

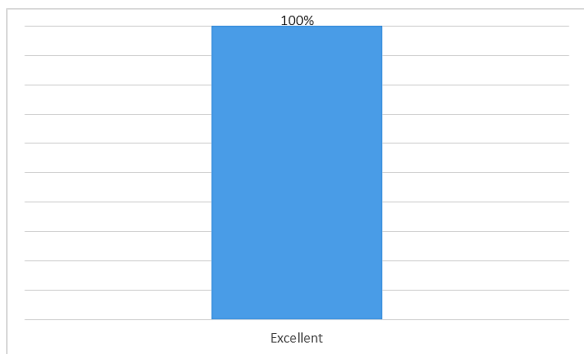


Fig. 8 Percentile representation of certain Nera water classes according to Nejebauer classification, vegetation period 2007-2017

According to SWQI methodology the quality of water varied from varied from "good" to "excellent". Half of the samples were characterized by excellent quality, about 40% of the samples belonged to the class of "very good" and about 10% of the class of "good" water (Fig. 9).

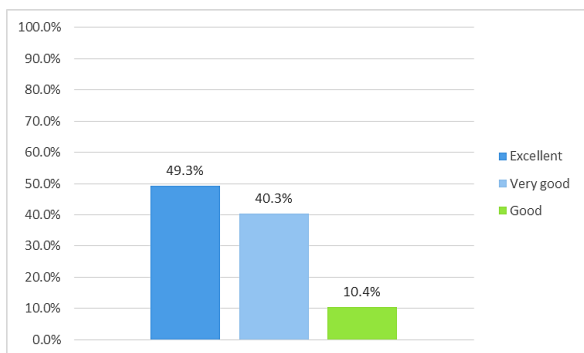


Fig. 9 Percentile representation of certain Nera water classes according to SWQI methodology, vegetation period 2007-2017

Table 9 shows the minimum, maximum and mean value of the Nera water quality index, as well as the standard deviation value. The average value of the index, although indicating "very good" quality, is at the "excellent" quality limit (90). The average values for each analyzed month and their descriptive indicator are shown in Table 10.

Table 9 Minimum, maximum, mean and standard deviations (SD) SWQI of Nera, vegetation period April-September, 2007-2017

	SWQI
Minimum	77
Maximum	97
Mean	89
Standard Deviation	4

Table 10 Average monthly values of the Water Quality Index of Nera, vegetation period 2007-2017

	April	May	June	July	August	September
	85	82	80	79	79	84
	Very good	Good	Good	Good	Good	Very good

CONCLUSION

According to all water classifications, the analyzed watercourses are usable for irrigation, where the best quality is characterized by the Nera water, then Karas and Moravica. All three watercourses require control over the content of total salt, due to the impact on soil and plants, as well as the ratio of sodium concentration to calcium and magnesium (SAR value), due to a moderate danger to the infiltration properties of the soil. Special control is needed on the concentration of bicarbonates from which there is a greater risk of occurrence of various adverse effects on the soil, irrigated plants and irrigation equipment.

The results according to the Nejebauer classification adapted to the conditions of Vojvodina are most favorable for use. According to this classification, the quality of Moravica is "good" (II class) to about 80% of the samples, the remaining samples were "excellent" quality (class I), except for one unsuitable for use, while Karas and Nera, their samples are classified as 100% in the "excellent" class of quality (class I). Although it may give the most benign results because it is adapted to the natural characteristics of the area being analyzed, it includes a modest amount of data for classification.

The FAO classification is more detailed, but like the USSL classification of a different local character, the direction of future research could be directed to modification towards the natural factors of Vojvodina.

The SWQI methodology includes a wider range of parameters being analyzed, but not all of them are of paramount importance for irrigation purposes, nor are the class boundaries defined accordingly. However, the occasional analysis of these parameters is desirable, with the possible adjustment of the border values for these purposes.

Acknowledgement

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