JOURNAL OF ENVIRONMENTAL GEOGRAPHY
Journal of Environmental Geography 11 (1–2), 1–8.
DOI: 10.2478/jengeo-2018-0001
ISSN: 2060-467X

NATURAL HAZARDS IN SAO VICENTE (CABO VERDE)

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Research article, received 11 November 2017, accepted 6 February 2018

Abstract

São Vicente island (República de Cabo Verde) lies within the Sahelian zone and faces a number of natural hazards, of which the most significant ones are erosion and gully formation, desertification and flash flooding hazards. Based on examples, we set out to examine the main factors involved in the development of these natural hazards from a regional point of view, while simultaneously assessing the importance of anthropic action as a structural factor. The investigation of Lazareto's gullies (located to the west of Mindelo) aimed to determine the main factors of the gullies formation. It also sought to demonstrate that the gullies' formation is a reliable indicator of the high rates of erosion on a regional scale. The approach to the desertification hazards was based on farmers' perception related to the evolution of agricultural production, strategies to mitigate drought and desertification issues, consequences and future prospects based on a set of interviews conducted in Ribeira da Vinha. Finally, the intense rainfall event that occurred on August 26, 2008 was analysed to identify the main vulnerability factors of the city in light of the flash flood hazard.

Keywords: São Vicente (Cape Verde), risks, vulnerability, flash flooding, gullies formation

INTRODUCTION

São Vicente faces a number of natural hazards, particularly erosion and gully formation, desertification and flash flooding hazards (PANA, 2004). As the archipelago of Cabo Verde lies within the Sahelian zone, it is in a region at high hazard of erosion with serious consequences for the productive capacity of the soil. The steepness of many slopes, the poor vegetation cover, the irregular and concentrated precipitation are the most important factors for explaining how erosive processes are manifested.

In rural areas, degradation of the soil is certainly one of the more restrictive phenomena for occupation of the territory and rural development due to the reduction of useful agricultural space (Costa, 1996). Besides the climate, agricultural-forestry-pastoral over-exploitation also helps to accentuate the erosion hazard. In these conditions, run-off is particularly effective, making use of the slopes with little or no vegetation cover, the absence or thinness of the soil and presence of thick surface formations, creating a relief marked by furrows and gullies. Drought and desertification are other serious concerns induced by lifestyles based on agriculture and/or livestock and which may also be linked to urban growth, which generates major environmental and social consequences that are hard to quantify and assess (SEPA, 2000a; Ferreira et al., 2013).

Damage caused by drought is generally resolved with short term palliative interventions, even though they need to be repeated periodically over the years. Desertification has more severe origins, connected to erosive processes that contribute towards the loss of humidity in the soil, which reduces its availability for vegetation, even in years with more rainfall.

The only incontestable proof of desertification for a given area would come from experimental fields, in which all the factors which influence production, except environmental factors, have remained constant for a period of time of never less than a decade, so that it would cover dry years and rainy years (Warren and Maizels, 1992). Although the quantification and strict definition of the areas subject to the process of desertification are difficult to define in Cabo Verde, numerous areas have suffered severe damage with the natural loss of productivity and environmental recovery processes should be undertaken in São Vicente (SEPA, 2000a).

There are many methods of assessing the soil's loss of capacity and the levels of desertification and they take different approaches (Hare et al., 1992), which are influenced by the concept itself, but which, generally, in more advanced states include gullies. In the initial states the signs are more subtle and easier to correct. Therefore, the assessment methods include signs indicating a disturbance in the balance of the ecosystem on the one hand, and, on the other hand, indicators of the levels of severity and recovery (Warren and Maizels, 1992).

On land lacking any protection strategies the rain erosion hazard is high in the sub-humid fringes, due to the greater frequency of concentrated rainfall in the wetter areas. In contrast, wind erosion constitutes the greatest hazard in the drier areas of Cabo Verde because the surfaces in these more arid areas are poorly compacted.

However, very often the processes combine and so in São Vicente we frequently find signs of water and wind erosion in different morphoclimatic contexts. Stony soil is common in arid spaces and results from the combination of wind and rainwater runoff erosion, leading to the formation of ground surfaces similar to those in deserts. Gullies often form on sub-humid slopes and in the areas at the bottom of the slopes, which makes it practically impossible to use them for agriculture.

The soils are generally of fine texture with low permeability, with poor infiltration capacity. When precipitation occurs, and because of the low infiltration capacity, the runoff helps to reduce the water that could be made available for vegetation. The way the landscape evolves and the role of erosion in the productive capacity of the soil will therefore largely depend on anthropic action. This should take into consideration the vulnerability of the ecosystems of the dry lands, particularly where vegetation is sparse as it offers practically no protection to the soil against the runoff.

In urban areas, rapid construction increases the flash flooding hazard and is one of the most important factors in increasing vulnerability (Monteiro, 2007; Andrade and Silva, 2017). The aim of this investigation was to understand the main factors involved in the development of the erosion hazard and gully formation, together with the dangers of desertification and flash flooding, from a regional point of view. It also set out to assess the importance of vulnerability as a structural factor in the overall dimension of the hazards.

The gullies of Lazareto, to the west of Mindelo, were therefore assessed so as to understand the factors influencing their origination. Furthermore, the work showed that gully formation is a reliable indicator of high rates of erosion on a regional scale. The approach to the desertification hazards was based on farmers' perception related to the evolution of agricultural production, strategies implemented to mitigate the desertification hazard and the consequences of falling productivity on farms in. Finally, the episode of intense rainfall that occurred on August 26, 2008 was studied in order to identify the main factors and the vulnerability of the city in the face of the flash flooding hazard.

STUDY AREA

Located in the Atlantic Ocean, with latitude situated between parallel 17°12' and 14°48' north and longitude which extends from 22°44' to 25°22' west of Greenwich, the archipelago is composed of ten islands and eight minor islets arrayed in a west-facing horseshoe formation. The islands are traditionally divided into the Barlavento (windward) group that includes the islands of Santo Antão, São Vicente, Santa Luzia, São Nicolau, Sal, and Boa Vista, and the Sotavento (leeward) group, comprising Maio, Santiago, Fogo, and Brava.

From a structural point of view, the archipelago is located in a continental interpolate situation (Enrst and Buchan, 2003), whose genesis would be related to a hotspot mechanism (mantle plumes); a ridged connection of the basement rocks can be seen between the archipelagos of Cabo Verde and the Canary Islands

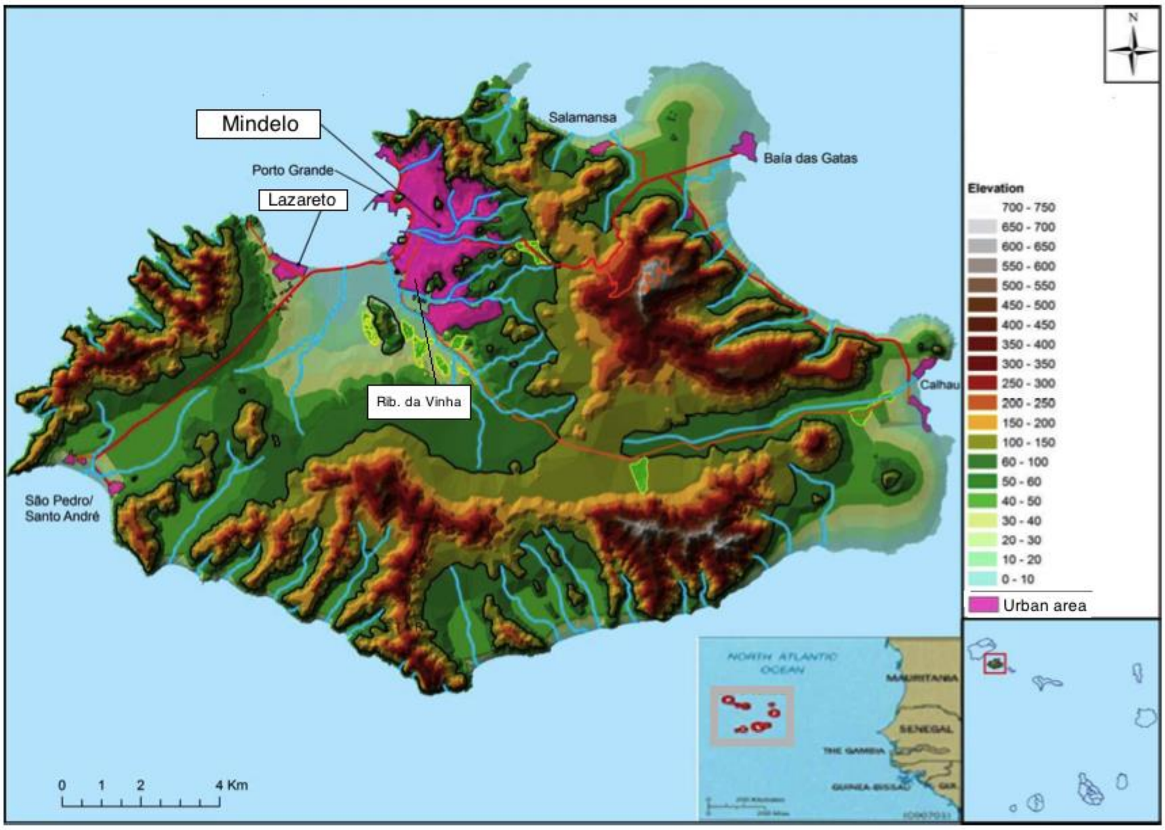

Fig. 1 São Vicente and its location in the archipelago of Cape Verde. Source: Adapted from Andrade and Silva (2017)

(Patriat and Labails, 2006; Holm et al., 2008). The Cabo Verde islands would have originated from the fragmentation of an ancient subcontinental mantle, when forming an oceanic mantle during the opening of the Atlantic Ocean (O'Reilly et al., 2009). The hotspot type activity would have begun around 19 to 22 million years ago and resulted in an uplift crustal area in which the archipelago is implanted (Plesner et al., 2002), with volcanic activity still a feature today. The tectonic activity is highlighted with the presence of inter-Atlantic transforming rift faults, important lifting processes and a main regional alignment in a NW-SE direction, and NNE-SSW tectonic structures (Victória, 2013).

São Vicente has a diversified morphology reaching altitudes of 744 meters in Monte Verde and 395 meters in Monte Topona. The city of Mindelo is surrounded by slopes that correspond to what remains of the volcano that originated the island and serves as a limit to the city (Fig. 1).

The archipelago of Cabo Verde falls within the so-called Sahel climatic belt, with an arid and semiarid climate. Rain is scant and highly variable. In general, rain falls in the form of showers, at times in heavy downpours that can reach values equal to or above monthly mean values. The rainy season runs from August to October, and can sometimes start in July, associated with the intertropical convergence zone, when this is further north (Amaral, 1964; Ferreira, 1983). However, the archipelago lies on the fringe of the main convective intensity, which explains the high variability of precipitation over the years. In the dry season, the islands are under an anticyclonic influence, with winds blowing from the northeast – the trade winds. Between December and June three types of weather are frequent: (i) "wintering" (December to March); (ii) "dry weather"; and (iii) the "westerly winds" (Amaral, 1964).

The average monthly temperature varies from 22 ºC in January and February to 27 ºC in August and September. These last two months are also the months where the precipitation values are higher. Rainfall events occur with great intensity. The average annual precipitation is 51 mm. According to the Thornthwaite climatic classification São Vicente has an arid climate.

METHODOLOGY

Analysis of three different hazards required different methodological approaches. For land cover determination downloaded satellite images from LANDSAT 8 were used with the Raster Calculator function available in the QuantumGIS 2.2 Valmiera software. Two maps (NIR and SWIR composition) with a supervised classification and natural composition using the Pan-Sharpening methodology were generated. This methodology allowed a higher resolution images which were then used to the definition of the land use areas.

Gullies located to the west of Mindelo were assessed in the field to ascertain the influencing factors. Twenty-two samples of soil sediments were randomly collected from the area where the gullies have formed. Both surface and depth sampling were used, taking advantage of the gullies' lateral walls to determine granulometric parameters. The Wentworth scale was used for particle size analysis. The fine fraction corresponds to the sum of the elements of less than 0.063mm in size (silt-clay fraction). Summing the different fractions we obtained a final weight which, when subtracted from the initial weight, results in the loss by analysis, thus allowing possible errors to be controlled throughout the process. The cumulative curves resulted from the sum obtained for each fraction in relation to the weight sieved, being made up from the thicker elements (2mm). Measurements were subsequently taken that describe the granulometry of sediments with central tendency (median Mdø, mean Mø, graphic mean Mz and trend), dispersion (calibration σ), asymmetry (Ski) and angularity of the curve (kurtosis).

The approach to the desertification hazards was based on farmers' perception analysis of productivity and strategies to mitigate the potential loss of the soil's productive capacity. In this order, 12 actions were held for farmers in Ribeira da Vinha. Regarding the observer's participation, it was a "non-participant observation", given that we were to remain outside the reality being studied, without interfering or becoming involved in the situation, i.e., it is the community that experienced the situation that will provide us with the information. In terms of the number of observers, it was a team observation, which we have also called "shared", given that it was conducted by both authors of this paper. It was a "field observation" because it was done at the location of the phenomenon. This classification is also supported in the ideas of Lessard-Hébert et al. (2005) in which the authors refer to "participated observation". This is because the facts are presented based on the information from the observed subjects, although the latent phenomena have been taken into account by us as observers of the phenomenon. Thus, there was a face-to-face relationship in the quest to rebuild the inhabitants' everyday life. In brief, this research was based on three pillars: direct observation of the phenomenon (interviews with the involved individuals); field survey; own perception based on a combination of the collected information. There were semi-directed individual interviews, given there were some pre-determined questions: (i) how farmers perceive the trend in agricultural production; (ii) what measures have been taken to mitigate the problems related to the decline in agricultural production; (iii) the farmers' future prospects. A logbook was written, recording our perceptions of the events, according to a reference table planned ahead of the trip and the field work.

Lastly, observation of the manifestation of the flash flooding hazard in the city of Mindelo on 26 August 2008 helped to identify the spatial location of the events that occurred and, therefore, to estimate the area, the most susceptible to its occurrence. It also helped us to gain a better understanding of the manifestation of the process and, in this way, to better estimate the consequences in the event of the repetition of similar situations. The rainfall amounts on that day and on the days prior to the event, and also the synoptic descriptions were kindly provided by the National Meteorology and Geophysics Institute of Cabo Verde.

RESULTS AND DISCUSSION

Erosion hazard and gullies formation - the example of the gullies of Lazareto (NW of São Vicente)

Periods of intense and concentrated precipitation contribute towards the significant loss of soil and generate powerful torrents due to the steep slopes that are filled with small materials, as a result of the poor vegetation cover (Fig. 2), which lend particularly active dynamics to the water courses. It is a common sight in São Vicente to see these streams reaching the sea loaded with solids, giving the water a yellowish-red tonality, principally near the outflow of the streams (Fig. 3).

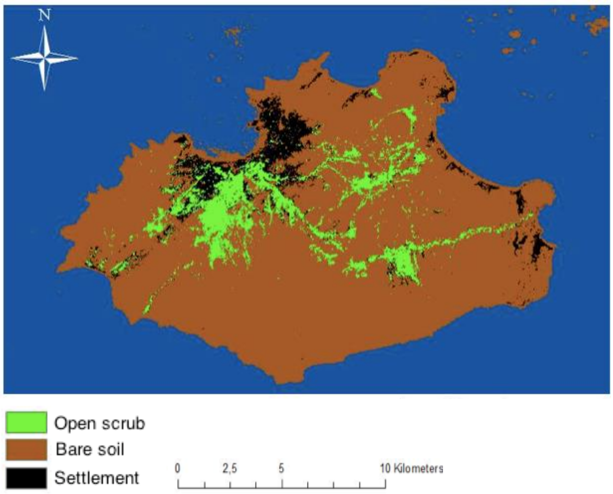

Fig. 2 São Vicente land use map based on LANDSAT 8 image

We can frequently observe gullies that are generally associated with problems of erosion, especially, when they affect areas of cultivation of high economic value. Unlike other processes associated to erosion by water like, for example, the rill formation, gullies imply much greater effort of control and erosive correction. In fact, studies developed to mitigate and prevent the effects of erosion attribute severe and often permanent damage to the land due to the action of creating gullies (Desta and Adugna, 2012). Even without affecting areas of cultivation, the gullies in the area of Lazareto, in NW São Vicente, confirm the importance of erosive processes, as they develop in the area at the foot of the slopes, situated to the east of the edge of the crater that borders the island to the northwest (Fig. 4).

Fig. 3 Terminal sector of a stream on Laginha beach. Note the orange tonality and the materials deposited at the outflow of the stream

The deepening and development of the network of gullies essentially depends on the presence of colluvium. In general, colluviums are very heterogeneous varying in size from over a metre to just centimetres with a varied degree of rolling, containing highly rolled blocks and others less so, while the basis is fundamentally formed by coarse sand. They can be more than 3 meters deep, comprising basaltic, conglomeratic material, of pebbles and rocks of black to dark grey in colour that are generally

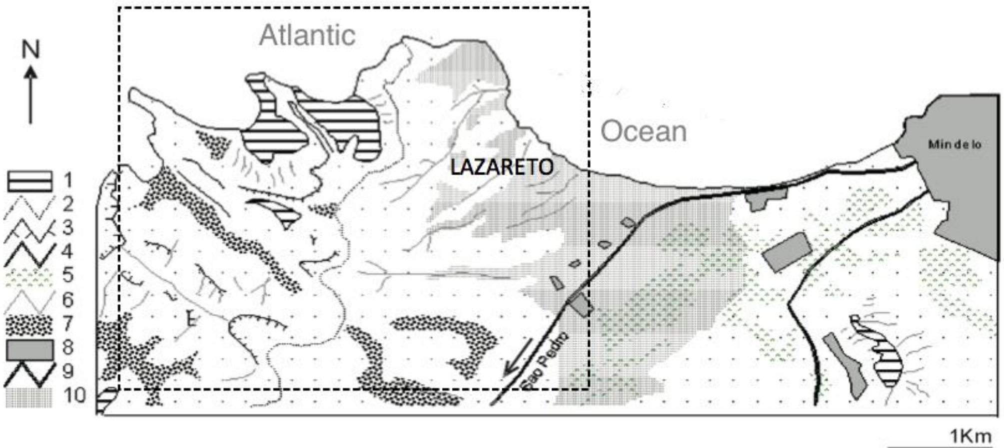

Fig. 4 Lazareto gullies location. Morphological features with land use information based on 2004 aerial photographs with field verification (extracted from Martins and Rebelo, 2009). 1 – Siliceous structural plateau; 2 – siliceous concave slope; 3 – escarpment; 4 – deep groove; 5 – vegetation; 6 – gullies; 7 - alluvial ejection cone; 8 – settlement; 9 – road; 10 –deep soils with open scrub.

well conserved (W1). The rocks generally have a disorganised disposition, especially the larger ones. Occasionally we observe interwoven stratification. The larger rocks are over one meter in diameter, with a great deal of heterogeneity regarding the degree of rolling, some with rounded edges, indicating that they were transported and subsequently deposited. Usually occupy a higher position to wind-blown deposit from the stratigraphic point of view (Fig. 5).

Wind-blown deposits correspond to conglomeratic sand dunes from the Quaternary period (Romariz and Serralheiro, 1967; Pereira, 2010), fundamentally made up from well calibrated sand which, in some sectors, can be over 30 meters deep. They are quite well stratified. Sand predominates (sample trend = 0.5mm) containing bioclasts, mineroclasts and lithoclasts of clear basalt, yellowish to beige in colour.

Figure 6 shows the curves and graphic illustration of some granulometric descriptive measurements obtained from the mean of the samples collected from the colluvium (Fig. 6A) and from the wind-blown sands deposit (Fig. 6B).

Colluvium occupies a higher position generally comprising sandstone and brownish clay/silt deposits, with a basaltic structure. They include sand and small rocks of a basaltic nature, sub-rolled and sub-angular not exceeding 5 cm in diameter. The volume of colluvium, the presence of wind-blown sand and the network of gullies are a reliable indicator of the high rates of erosion on a regional scale. The presence of very deep, recessed gullies, some of which are over 3 meters deep, also suggests a process of densification and recessing associated to each rainy season, confirming the concentrated surface runoff as the main agent of erosion, in particular, in movable materials which, given the absence or scarcity of vegetation together with the weakness of the soil (fine texture and low permeability), has a high intensity of mobilization of detritus.

Fig. 5 Typical profile where we see colluvium and lower down wind-blown deposit. The box of the camera surrounded by the circle serves as a scale

The desertification hazard

Although agriculture occupies only 9,6% of the surface of the country, this activity represents one of the most important sectors of primary production in the archipelago's socioeconomic development. In the years with the best agricultural results, almost always in line with the quantity and spatial and temporal distribution of the rains, significant changes in macroeconomic

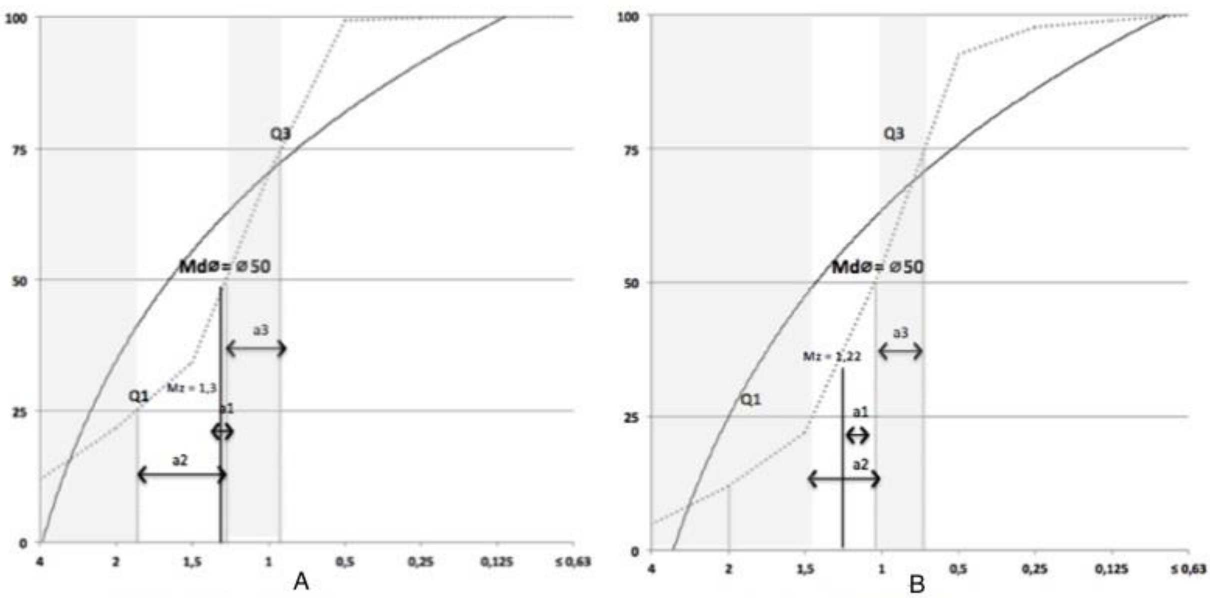

Fig. 6 Granulometric curves and graphic illustration of some descriptive measurements of these curves for the deposits: colluvium (A) and wind-blown (B) (Mdø: median, Mz: graphic mean, a1: distance between Mdø and Mz, a2: distance between Q1 and Mdø, a3: Mdø and Q3, Ski: asymmetry, Kg: angularity of the curve (kurtosis))

indicators are recorded, both in inflation and in the purchasing power of consumers, arising from the reduction in market prices (SEPA, 2000b and 2000c). On a national level, dry farming is predominant, and is used in over 75% of farms. Irrigation farming represents only 17% of farms and agroforestry is below 2%. However, the island of São Vicente does not reflect this distribution. The number of dryland farms does not exceed 6%. The farms are mainly irrigated farms and are concentrated around the Vinha streams, to the west of Mindelo.

Based on the interviews, irrigation systems that use shallow water wells are at hazard of the salinization hazard, resulting in a drop in production and the consequent abandonment of farms. In these cases, several farmers immediately moved to the urban centres or considered emigrating in the hope of improving their living conditions. However, irrigation using water from the ETAR (water treatment plant) of Vinha had a significant impact on the medium and long term prospects. The use of water from the ETAR helps to increase the agricultural production of vegetables. Currently, more than 40% farms now obtain their water from the ETAR.

Poor management of water from the ETAR and the investment needed to make the irrigation system more efficient are the major concerns mentioned by the farmers. The investments made are high, at times requiring loans, which puts some investors off. The water distribution technique is generally drip irrigation, involving setting out piping to transport the water, which implies enormous investments, both at the outset and *a posteriori*, in maintenance. This method is used by the majority of the farmers. It consists of releasing water at frequent intervals at strategic points located close to the roots. It also allows the water supply to be adjusted to the soil's absorption capacity and to the seasonal needs of the crops. All the farmers unanimously reported that, based on this irrigation system, production is more regular and has been increasing.

The interviews led to the recognition that the farms affected by desertification are reflected in the decrease in agricultural profitability, as well as in the consequences associated with migration.

Investigation also shows that abandoning farmland did not resolve the problem of desertification since these problems remain in most farms, especially those which are not investing in irrigation systems. The use of water from the Vinha ETAR was positive as an alternative, although it requires investment, which is a serious obstacle for a good number of the interviewed farmers. The absence of the government is a concern for the farmers interviewed.

The flash flooding hazard – the example of that occurred on 26 August 2008, in Mindelo

The city of Mindelo is surrounded by slopes that correspond to what remains of the volcano that originated the island of São Vicente and that forms the city limits. Rapid urban growth which on average is higher than the growth of the archipelago's population (Fig. 7), has meant that the construction of dwellings and thoroughfares now occupy areas that often correspond to small stream beds that are dry for most of the year, at times for years, but which rapidly fill up when there is more intense and concentrated rain (Rebelo, 1999).

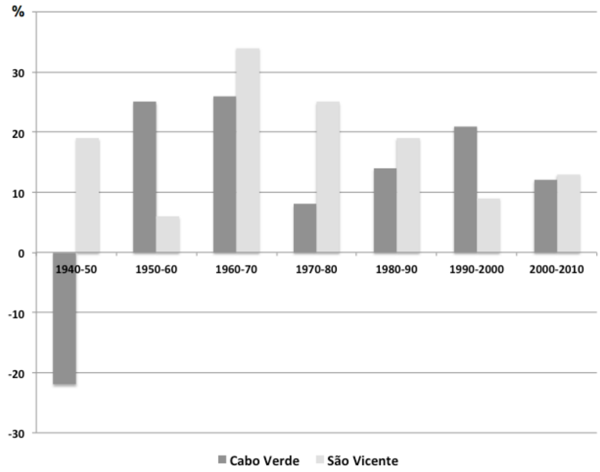

Fig. 7 Comparative analysis of the growth of the population in the island of São Vicente and in Cabo Verde, by decade, between 1940 and 2010. Data source: INE-CV.

This process of urban growth, devoid of planning, is one of the most important factors in the increase in vulnerability to the flash flooding hazard. Besides dwellings, many of the avenues and streets are badly affected by flash flooding, as is the case of the Rua do Côco, which leads to the central hospital of Mindelo, Baptista de Sousa.

There are countless examples of clandestine constructions that occupy areas subject both to flash flooding and mud flows. It then becomes very interesting to observe the large channels that cross the city and which, although of varying sizes, were built with the same objective, of leading the rainwater to the sea, but are frequently occupied by dwellings or even truncated by avenues and roundabouts.

In the case of Mindelo there are therefore factors related with the actions of humans that accelerate and exacerbate the consequences of physical processes.

The flash flooding on 26 August 2008 caused enormous material loss. Rainfall amounts in the form of showers were over 35mm (Fig. 8). This was an episode of rainfall associated with two cells of low pressure, with greater incidence in the region south of Cabo Verde, which led to the development of convective cloud formation namely cumulonimbus (Cb). Levels of humidity of over 85% were recorded in the whole of Western Africa and strong nuclei of vorticity and well defined cyclonic circulation. There was also a tropical wave on the east Atlantic (precisely southwest of the archipelago), moving in a north-easterly direction, and the positioning of the intertropical convergence zone (ITCZ) along an alignment defined by the coordinates 07°N52°W/9°N34°W/16°N25°W and with disperse convection in its central axis (information obtained from the National Meteorology and Geophysics Institute of Cabo Verde).

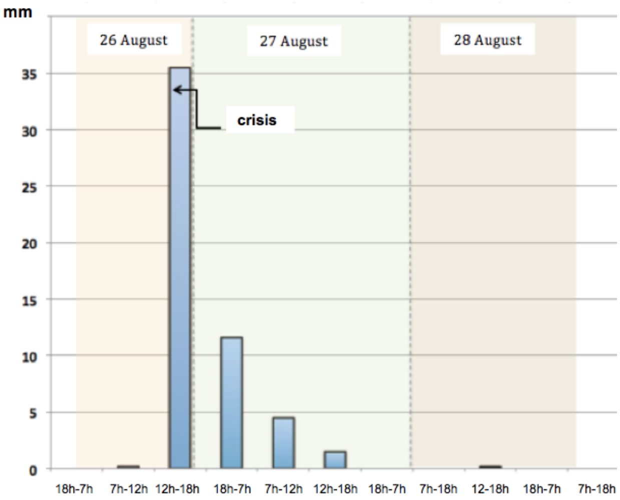

Fig. 8 Precipitation distribution (mm), in different intervals, in the weather station of the city of Mindelo, on 26 and 27 August 2008. Data source: INMG-CV

Although the precipitation resulting from this meteorological situation may have been a major factor in triggering the whole process, it cannot be the only explanation for what happened. In fact, slopes and soils with poor infiltration capacity, together with the morphological characteristics of the city and, above all, the significant increase in the constructed surface area which, in turn, increases the impermeable area, mean that more water remains on the surface and increases the speed of the river water, namely when full, thereby making the runoff process more violent. From the point of view of preventing this hazard, measures have to be taken that delay the runoff's response to intense rain, increasing the time of concentration and, therefore, reducing the velocity of the surface runoff.

However, the disorganised growth of the city contributed towards the destruction of important drainage channels, built with the intention of channelling the surface waters and also increasing the drainage speed, so it would reach the sea more quickly. Therefore, although the process or physical phenomenon has remained practically unchanged an inadequate response strategy significantly increases the hazard consequences.

In order to mitigate the effects of flash flooding hazard, in December 2010, the Town Hall of São Vicente carried out some torrential correction works, one of the main ones being the construction of dikes in the upper reaches of the water courses and drainage channels in the Rua do Côco and near Praça Estrela (Fig. 9). While these works are considered to be effective in hazard mitigation, rainfall crises continue to occur in various areas of the city of Mindelo, as was the case of the flash flooding in September 2013 (Fig. 10).

The losses were only material, but they showed that the drainage system is still insufficient. On the other hand, for the same intensity of rain we see that the flash flooding hazards have unfortunately increased.

Fig. 9 Torrential correction works near Praça Estrela in December 2010

Fig. 10 The flooding of the Rua do Côco in September 2013

CONCLUSION

As the archipelago of Cabo Verde is inside the Sahelian zone, it is in a space of high erosion hazard with serious consequences for the productive capacity of the soil. Periods of intense and concentrated precipitation play a part in significant loss of soil and generate powerful torrents as a result of the poor vegetation cover. The network of Lazaretto gullies is a reliable indicator of the high rates of erosion on a regional scale. The presence of very deep, recessed gullies, some of which are over 3 meters deep, also suggests a process of densification and recessing associated with each rainy season, confirming concentrated surface runoff as the main erosion agent, particularly with respect to movable materials.

The interviews led to a recognition that the farms affected by desertification are reflected in both the fall in agricultural profitability and the consequences associated with migration. Our research also shows that the abandonment of agricultural fields did not solve the problem of desertification since most farms still suffer this problem, especially those which are not investing in irrigation systems. The use of the water from the Vinha

ETAR was positive as an alternative, although it requires investment, and this is a serious obstacle for many of the farmers we interviewed. Most farmers feel there is too little government support.

Disorganized urban growth is responsible for the increased flash flooding hazard through the destruction of important drainage channels that were built with the intention of channelling the surface waters and also increasing drainage speed, so the flow would reach the sea more quickly.

In climatic zones subject to intense erosive processes and where the ecosystems' response to anthropic interventions is very sensitive, as is the case of the island of São Vicente, action in the territory should be cautious. In fact, the growing abandonment of agricultural-pastoral activities will not resolve the problems, quite to the contrary, as the abandonment of agricultural areas and the consequent rural exodus may increase the vulnerability of the urban areas, in particular, in the larger cities, as is the case of the city of Mindelo.

Acknowledgements

The daily rainfall amounts for 26, 27 and 28 August 2008 and the synoptic surface situation for 26 August 2008 were kindly provided by the National Meteorology and Geophysics Institute of Cabo Verde, to whom we express our gratitude.

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JOURNAL OF ENVIRONMENTAL GEOGRAPHY
Journal of Environmental Geography 11 (1–2), 9–16.
DOI: 10.2478/jengeo-2018-0002
ISSN: 2060-467X

DEVELOPMENT OF STREAMBED POTHOLES AND THE ROLE OF GRINDING STONES

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Research article, received 22 January 2018, accepted 28 March 2018

Abstract

The largest grinding stone episodically stored in pothole is not only responsible for growth of pothole size but also determines its shape. This paper examines the largest grinding stone found in cylindrical potholes and their role in pothole growth using empirical analysis. The largest grinding stone from 34 randomly selected potholes, developed on the riverbed of Subarnarekha River at Ghatshila, Jharkhand, India, were analyzed to have an insight into 1) their sizes and shapes; 2) controls on grinding stone shape; and 3) roles of largest grinding stone on streambed pothole growth. Strong correlation coefficient between the size and weight of grinding stones reveals their similar specific gravity. The pothole depth was proportional to the diameter of the largest grinding stone in it. Concave pothole-floors developed because of abrasion by grinding stones atop floor. A force applied on largest grinding stone depends upon not only eddy velocity within pothole but also on shape of the stone.

Keywords: potholes, largest grinding stone, shape of grinding stone, eddy velocity

INTRODUCTION

Potholes are the most spectacular features in bedrock river channels. Currently potholes are studied extensively and considered as key factor in bedrock channel development and morphology (Hancock et al., 1998; Whipple et al., 2000). Potholes along with other sculpted forms in bedrock channel can be tied to river hydrology (Blumberg and Curl, 1974; Curl, 1974). Bedrock channels with higher velocity and hydraulic radius (Reynold's number > 2200) are characterized by turbulent type of flow which leads vortex / whirlpool motion and formation and growth of potholes.

Springer et al. (2005) established relationship between average radius ($\bar{r}$) and depth (d) of potholes and expressed the relation as $\bar{r} = kd^{\varepsilon}$. They considered the potholes as radially expanding cylinders and designed a growth-model on geometrical base. Pelletier et al. (2014) also showed that pothole depth (d)increases in proportion to both the mean pothole radius ($\bar{r}$)and the diameter of the largest grinding stone episodically stored in potholes.They also modeled a limit of depth to mean radius ratio (γ) beyond which bed shear stress (τ) become too small for abrasive work atop floor of the pothole and designed formula of minimum water depth for development of pothole of given radius on given slope. Yet numerous questions concerning discrete erosion phenomena remain unanswered (Whipple, 2004). For example, how pothole size related to stream power? How vortex velocity within pothole varies with rising river velocity and increasing $d / \bar{r}$ ratio? With given stream flow velocity, how vortex velocity changes with increasing pothole depths? How long the positive feedback between growth of potholes and vortex velocity (Allen, 1968; 1971; Blumberg and Curl, 1974; Hancock et al., 1998) goes on? Moreover, to entrain stones from bottom of pothole for episodic abrasion (and shaping of stones), Rouse number must be less than 7.5 (Julien, 1998) which increases with increasing $d / \bar{r}$ of a pothole and which in turn reduces the frequency and degree of abrasion by stones. So beyond $\gamma \sim 2$, largest stones remains relatively idle with rough and irregular shape.

The fundamental properties of sediments are size, shape, mineralogical composition, surface texture, and orientation. Sediment shape plays an important role in selective transportation of the particle. Settlement velocity of a sediment particle is again controlled by size, shape, and density of the particle. Thus the shape, along with size and density, shed light not only on the transportation history of the deposit, but also on the immediate conditions at the site of deposition (Knighton, 1998). Pebbles or boulders from various environment are examined by Gregory and Cullingford (1974), Carroll (1951), Carroll et al. (1950), Plumlley (1948), Allen (1949), Krumbein (1940, 1941a, b), Zingg (1935), Luttig (1962), Bluck (1969), Tricart and Schaeffer (1950), Riviere and Ville (1967), Flemming (1964), Lees (1964) and Folk (1972). Using roundness measurement, [(2r/L) × 100], Gregory and Cullingford (1974) distinguished between till and fluvioglacial material and found lateral variation in pebble shape in northwest Yorkshire. Carroll (1951) examined variation in shapes and roundness of pothole pebbles collected from Valley of the Waters, Wentworth Falls, in the Blue Mountains. Experiment done by Rayleigh (1942, 1944) reveals that spherical pebbles are scarce. Pelletier et al. (2014) found relation between the largest grinding stones diameter and pothole depths.

In western India, potholes at Indrayani knick point are studied by Sengupta and Kale (2011), Kale and Gupta (2001) and Kale and Joshi (2004) and established evidence of formation of potholes in bedrock on human timescale. But shapes of grinding stones responsible for shaping those potholes are not examined. So present study illuminated size and shape of the largest grinding stone in potholes and its role in pothole growth.

IMPORTANCE OF GRINDING STONES IN POTHOLE GROWTH

Potholes grow as a result of combined erosion of walls and floors. Efficacy of erosion phenomena (Springer et al., 2005) determines differences in erosion rate of wall and floor of the potholes. All type of sediments sizes stored in potholes and involved in erosion is collectively called stones (Gilbert, 1877). Suspended load-size stones (largely coarse sands) abrade on wall and increase the aperture of potholes. Bed load-size stones like cobbles and boulders (Knighton, 1998) on the other hand works atop floor of potholes are called grinders (Springer et al., 2005). Grinders roll, skip or slide to abrade atop floor of potholes to maintain depths with proportionally increasing radii. Springer at al. (2005) reported small potholes having slightly concave floor and larger potholes having slightly convex floor in the Orange River bed inSouth Africa. By inference, large bed load-size grinders are absent in small hemispherical potholes. As a result, dominant wall erosion gives the potholes hemispherical shape. Grinder on the other hand perceived as largely responsible for pothole growth (Springer at al., 2005). It is also reported that depths of potholes grow faster than radius. And as suspended load-size sediment mainly impacts on wall, they have little contribution in deepening the potholes. Rather, grinders working solely atop floors are largely responsible forpothole deepening. Grinding stones are swept around pothole floors and lower part of pothole walls. Centrifugal force applied on rotating grinders in persistent non-transient vortices abrade more along the circumference than center of the pothole floors. As a result, potholes with central boss (Morgan, 1970) and convex floor (Springer et al., 2005) are intuitively shaped by grinders' erosion phenomena. It was observed in some larger potholes that radius at the bottom are larger than radius of aperture. This larger radius towards bottom is largely because of abrasive works of bed load-size grinding stones.

Present paper examines the largest grinder found in each of the pothole and its role in pothole growth. Pelletier et al. (2014) observed that pothole depths increase in proportion to diameter of largest grinding stones episodically stored in potholes. Therefore, it is inferred that with uniform flow velocity of stream above potholes, vortices velocity increases with increasing depths of potholes and thereby entrapping larger largest-grinder. Largest grinding stone, if too large to move by vortex velocity within pothole, may protect the pothole floors from further erosion causing formation of central boss (Morgan, 1970) and convex floor (Springer et al., 2005).

But efficacy of erosion phenomena by largest stone or its role in shaping potholes depends not only on its size but also on shape. For example, two stones having equal sizes and weights may require different vortices velocity to be entrained if their shapes are different. For abrasion, the stone episodically stored in the potholes is to be entrained and set under eddy type of motion. To entrain a particle of sediment of volume 'V' density 'ρ' and diameter 'D', the force F of flowing water applied on it must equals its submerged weight $w_s = g(\rho_s - \rho_f)$. And this can be expressed as:

$$F = m \times a \quad (1)$$

where m = mass of sediment, a = acceleration.

$$F = \frac{m \times v}{t}$$

[∵a = v/t, v= velocity of water flow in river, t=time]

or $F = \frac{V \times d \times v}{t}$ [∵m = Vd]

or $$F = \frac{V \times d \times v}{t} \quad (2)$$

Suppose velocity 'v' of river flow is constant. Volume 'V' and density 'ρ_s' of sediment are also constant. Diameter 'D' of irregular shaped stones is under question because natural grinding stones are seldom spherical in shape. If long axis (L), intermediate axis (I) and short axis (S) of a stone (Fig. 1) of volume 'V' varied, amount of force applied on it also changes.

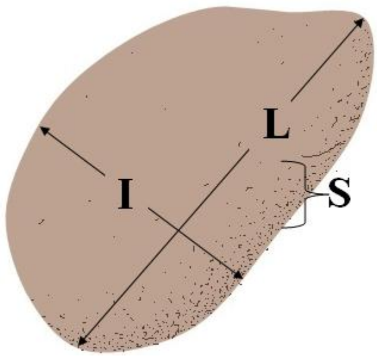

Fig. 1 Dimensions of the largest grinding stones in potholes. L: long axis (length), I: intermediate axis (width), S:short axis (height)

Drag force (Charlton, 2008; Knighton, 1998) applied depends on surface area (A) of the stones exposed to flow direction (Fig. 2). If L, I and S are unequal, then in normal condition, the stones will rest on the river bed with largest surface area (L×I) contact. Therefore if L and I are relatively small, the S will be relatively large causing higher force applied by flow of water on the stones and vice versa. Force applied by given flow velocity '*v*' on a surface area 'A= I×S' perpendicular to flow direction (although all the points of the surface of a natural grinding stone are not perpendicular to flow direction) was calculated as:

$$F = \rho A v^2 \quad (3)$$

Therefore, higher the surface area exposed to water flow, higher is the applied force to initiate entrainment of stones (Fig. 2). According to Figure 2 both the grinding stones A and B have same volume, density, mass and therefore equal frictional force against movement. But A is cubical and B is cuboidal in shape. River's uniform flow velocity 'v' shown by length of the blue arrows are applying force 'F' perpendicularly on surface area (I×S) facing flow direction. As surface area of stone A exposed to river velocity is greater than surface area of stone B exposed to river velocity, force applied on A is also greater than force applied on B. So critical velocity to entrain stone A is much less than critical velocity needed to entrain stone B. Surface area exposed to direction of water flow directly depends upon shape of the stones. It is maximum for spherical stones and minimum for planner and acicular stones (Zingg, 1935).

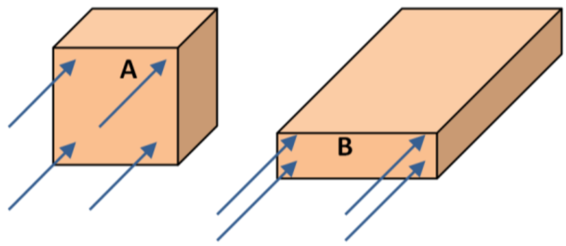

Fig. 2 Different surface areas of the cubical (A) and cuboidal (B) shape grinding stones exposed to flow direction

The shape of stones determines friction angle (Fig. 3) of sediments which in turn determines force applied on it which in turn determines momentum of stones without which carving of pothole is impossible. Therefore in equation (4), shape factor which is most appropriately represented by sphericity ψ was incorporated to find out critical force F_c needed to set a stone in motion. As sphericity of all natural river borne stones are less than 1, it reduces surface area of stones perpendicular to flow direction and in turn reduces drag force applied on stone.

$$F_c = \frac{\mathrm{V \times d \times v}}{\psi \times \mathrm{t}} \tag{4}$$

If velocity 'v' of the river is known, and if we can derive eddy velocity v_e within pothole with increasing aspect ratio γ (depth to width ratio) and once eddy velocity v_e is known, one can logically guess (using Hjulstrom's 1935 curve) about whether the largest boulder stored in the pothole have ever been entrained to abrade atop floors of pothole or it is lying inactively protecting the floors and giving it convex shape.

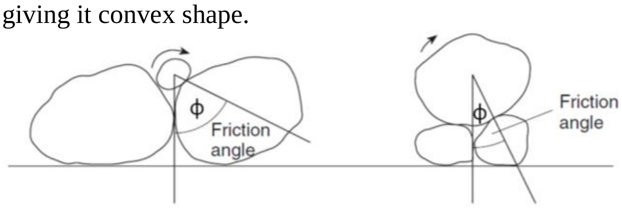

Fig. 3 Stones shape and size control friction angle which in turn determines their entrainment velocity and critical shear stress (Charlton, 2008)

Shear stress is regarded as the most important impelling force to set a sediment particle in motion. When critical shear stress τ_{cr} equals stones shear stress τ_0, stone starts to move. It is defined as:

$$\tau_{cr} = k(\rho_s - \rho_f) \times D \times g \text{ (Knighton, 1998)} \tag{5}$$

where ρ_s = density of sediment, ρ_f = density of water, D = diameter of sediment= $\sqrt[3]{L \times I \times S}$ (Williams, 1965) and g = acceleration due to gravity ($9.81 ms^{-2}$).

Putting the value of the given Shields parameters (k = 0.045 (Knighton, 1998) for pebbles and boulders) the equation (6) can be simplified as:

$\tau_{cr} = k(\rho_s - \rho_f) \times D \times g$ (Knighton, 1998)

or, $\tau_{cr} = 0.045\ (2700 kgm^{-3} - 1000 kgm^{-3}) \times D \times 9.81 ms^{-2}$ [average density of dolerite/ granite $2700 kgm^{-3}$]

or, $\tau_{cr} = 0.045\ (1700 kgm^{-3}) \times D \times 9.81 ms^{-2}$

or, $\tau_{cr} = 76.5 kgm^{-3} \times D \times 9.81 ms^{-2}$

or, $\tau_{cr} = 750.46 D$

Incorporating shape factor, the equation is given as:

$$\tau_{cr} = 750.46 \frac{D}{\psi} \qquad \left[D = \sqrt[3]{L \times I \times S}\right] \tag{6}$$

But submerged sediment weight is not only the resisting force to motion. Degree of packing 'ɳ'of sediment is of significant importance which in turn, to some extent, controlled by shape of stones (Fig. 3). Shape factor of sediment also exerts its direct influence on critical shear stress.

$$\tau_{cr} = \eta g(\rho_s - \rho_f) \times \frac{\pi}{6} \times \frac{D}{\psi} \times \tan\phi \tag{7}$$

where ɳ = a measure of grain packing, ϕ = friction angle. Stones shape in pothole therefore is of great significance which determines not only chance and frequency of entrainment of largest stones under given maximum river velocity but also of the smaller stones of different size and shape.

Therefore, sizes and shapes of bed load-size grinding stones (and largest grinder) are given importance because those are [1] determinant of drag force needed to initiate stones motion needed to abrade the floors, [2] restrainer of critical shear stress to set a sediment particle in motion, [3] responsible for increase in potholes depths,[4] responsible for convexity of potholes floors and [5] responsible for overall pothole growth (Springer at al., 2005).

STUDY AREA

In our study potholes in the Subarnarekha river bed downstream of Bhatajhor River confluence at Ghatsila were investigated. Subarnarekha river has a total length of 395 km, covering a drainage area of 18,951 km^2. After origin near Nagri village in Ranchi hill area at an elevation of 600 m (CWC, 2015), the Subarnarekha River traverses through Ranchi, Seraikela, Kharsawan and East Singhbhum districts in the state of Jharkhand, east India (Fig. 4). Thereafter, it flows through Paschim Medinipur district in West Bengal for 83 kilometres and Balasore district of Odisha for 79 kilometers to join the Bay of Bengal near Talsari. There is a small cluster of about 40 potholes in middle Subarnarekha river bed at the immediate downstream of Bhatajhor River confluence at Ghatsila, a town of East

Singhbhum District of Jharkhand in India. For this study, largest grinding stone was collected from each of 34 potholes from there (Fig. 4).

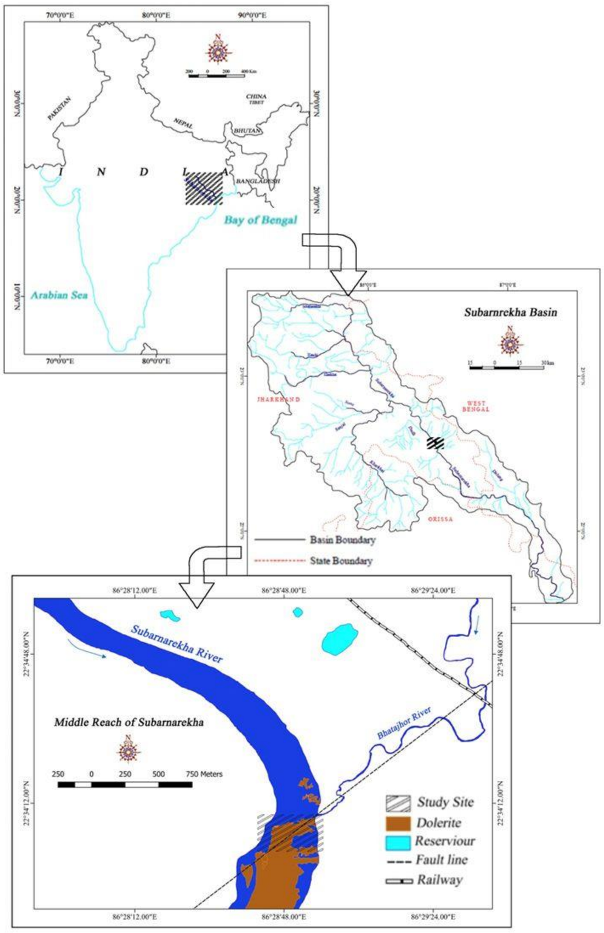

Fig. 4 Location of study area and the sampling site

There is a vast variation in peak water level which varies from 378.9 m to 8.9 m. Zero of the guage of the river Subarnarekha at Ghatshila was 72.00m and peak water level ever recorded was 85.05m recorded on 17.08.1974. Discharge recorded on that day was 9579.59 cumecs. Minimum water level 45.14m was recorded on 20.04.1972 when discharge was only 3.8 cumecs. Highest discharge ever recorded was 10582 cumecs on 06.08.1997 and minimum discharge ever recorded was 0.4 cumecs on 12.03.2010. So there was a high seasonal and annual variation in guage height and discharge. Average sediment load during monsoon months (2182000 metric tones) was 110 times higher than average sediment load during non-monsoon months (19800 metric tones).

Surface exposure of schist / phylite and quartzite of Singhbhum Group of rocks are recorded around Ghatsila, a town of East Singhbhum (Fig. 5) District of Jharkhand of India (GSI, 2006). Foliated mica-schists forms the bed of the river Subarnarekha. Foliations of schists dip 50˚ - 70˚ towards south and south-west. An arc of fault line East-North-West with doleritic intrusion runs across the river Subarnarekha at study site. Outcrop of doleritic dyke is aligned east-west across the river atop which potholes are sculpted. Dolerite substrate are characterized by vertical cross joints and cracks which facilitated potholes formation.

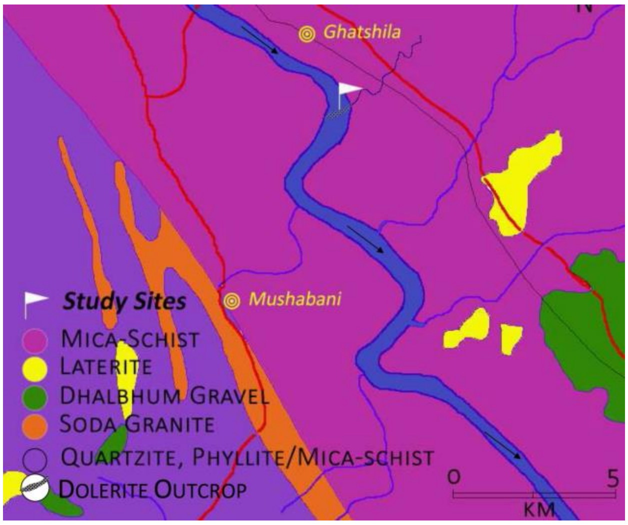

Fig. 5 Geological setup of the study area

MATERIALS AND METHODS

First of all, 34 potholes (more than 80% of the population of the study site) were selected randomly. Then those were numbered serially to avoid overlaping and gaping. Then diameters and depths of potholes were recorded (Fig. 6). Potholes with collapsed walls were not selected because it made difficulty in measuring their dimensions.

As materials for this study are data on different variables of largest grinding stone stored in potholes, Long axis (L) intermediate axis (I) and short axis (S) of stone (Fig. 1); volume, shape, weight, flatness and sphericity of largest grinding stone was recorded from each of the 34 potholes. Weight was measured by electronic balances of 1.0g to 500.0g and 100.0g to 15000.0g. Volumes were measured diping the stone into water and collecting the replaced water by stone in a graduated jar which gives volume of the stone directly. Absorption of water by dry stone affects volume of replaced water. So dry stones were first dipped into water before puting it into water of measuring device. Shape of stones are explained in terms of sphericity and flatness and measured using formulas of Krumbein (1941 a,b) and Cailleux (1945) respectively.

Sphericity (ψ) of the largest grinding stone was determined using the formula by Krumbein (1941). Higher the value ofψ, more spherical is the stone.

$$\psi = \sqrt[3]{(IS/L^2)} \quad (8)$$

Using ratio of intermediate axis (I) to long axis (L) and short axis (S) to intermediate axis (I) stones were classified (Zingg, 1935) into different sphericity classes.

Cailleux (1945) developed the flatness index (𝔽) based upon the relationship between the particle dimensions along the three principal axes. The index is given by

$$\mathbb{F} = \frac{L+I}{2S} \quad (9)$$

Theoretically, lowest value is 1.0, the higher the value more flat is the stone. The measure is opposite to the sphericity index. If sphericity of stones is greater, its flatness is less and vice versa. Roughness of pothole stones is the degree of irregularities in shape. It has opposit notion of sphericity. Roughness of stoness was measured using formula $R = \frac{L-S}{L}$. (10)

Fig. 6 A. Pothole where depth is greater when comparing to aparture diameter. B. Dimensions measured with the help of a specially devised instrument. C. Weight measurement of grinding stones D. Pothole almost full of stones quoted with mosses.

Out of the largest 34 grinding stones found in 34 potholes, the largest (amongst the 34 largests) was of diameter 19.89 cm. The stone was rounded and logically assumed that it was entrained by river velocity and was in abrasive action for pothole growth. Entrainment velocity (1.5 m^{-s}) for that largest stone was taken from Hjulstrom's curve (1935). Then forces applied by that given velocity 'v' (v = velocity 1.5 m^{-s} needed to entrain largest D=19.89cm of the 34 grinding stones was derived from Pjulstrom curve) on surface area 'A' (of all other grinding stones) perpendicular to flow direction (although all the points of the surface is not perpendicular) was calculated using equation No. 3.

RESULTS AND DISCUSSION

Potholes

Depths of potholes were from 17cm to 147cm. Average depth was 55.32cm and coefficient of variation of depth was 56.08. Out of 34 potholes, 16 potholes had depths less than 0.5 meters and rest 18 potholes had depths from 0.5 meters to 1.47 meters. Volume of potholes were from 0.005m^3 to 1.672m^3. Average volume of 34 potholes was 0.22 m^3. Median volume was found 0.081m^3. 30 potholes had volume less than 0.5 m^3 and only 4 potholes had volume above 0.5m^3. Only one pothole had its volume more than 1.0 m^3 and it was 1.672m^3.

Size, weight and shape of largest stones

Average size (volume) of 34 grinding stones is 1991.28 cm^3. The largest one is of 7873.60 cm^3 and the smallest one is of 83.64 cm^3. The greatest weight of stones (12096 g) does not correspond to the largest size of stone. Lowest weight of stones was recorded 83.3 g and average weight was 2950.48 g. There is a very strong correlation (R^2 = 0.94) between stones size and stones weight which indicates homogeneity of stones composition. There are two distinct clusters of stones (Fig. 6): one group of relatively smaller size and light weight having compact association. Perhaps these stones are working for a longer period within potholes and have got more sphericity (ψ = 0.66 to 0.88) in shape. Another group of five stones of larger size and heavy weight have relatively dispersed association. This is because larger stones may be the collapsed blocks of the pothole wall and have not experienced long abrasive action to be spherical (ψ = 0.46 to 0.62). Moreover, the larger five stones were of varying parent rocks (Dolerite-1, Quartzite-2, Schist-1, Granite-1).

Sphericity (ψ) indicates how long the stone was involved in pothole formation. Longer period the stone is engaged in abrasion of pothols, the stone is more spherical. Sphericity of stones ranges from 0.46 to 0.88. Most irregular stones with low sphericity were found in breached potholes (Richardson and Carling, 2005). Out of 34 grinding stones, 38.24% stones were found to be oblate shaped (Fig. 8), 26.47% stones were recorded as spherical while 23.53% and 11.76% were prolate and blade shaped respectively. Standerd deviation (SD) of ψ of 34 stones was 0.08 and coefficient of variation (CV) was 11.28 %. These imply that there was no significant variation in shape of the largest grinding stones of 34 potholes.

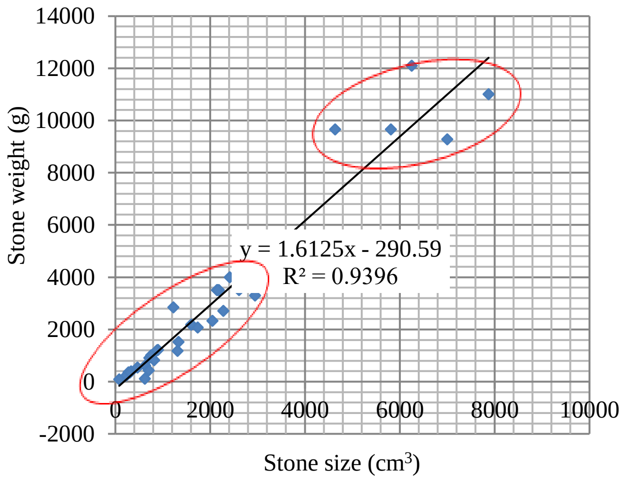

Fig.7 Relationship between stone size and weight: stone size and weight shows a strong correlation with a distinct variation between two clusters

Roughness varied from 0.78 to 0.17. Average roughness of stones was 0.50. Out of total, 25 % of observation have roughness less than 0.45. Half of the observations have roughness value less than 0.52 and 75% of the distribution have roughness value less than 0.55. Out of 34 grinding stones, 14 stones had roughness of <0.5 and rest 20 stones had roughness >0.5. Flatness and roughness of stones came from original shape of the clast and differential rate of abrasion. But long grinding reduced flatness of stones. Highest and lowest flatness were found 3.36 and 1.10 respectively with an average of 1.81. Sphericity (ψ) and flatness (𝔽) are opposit consideration about stones shape (Fig. 9) and finding of present study illuminate relation between them which is expressed as $\mathbb{F} = 0.989\psi^{-1.59}$ (R^2 = 0.78).

Sphericity and flatness of grinding stones are inversely related to each other. More flat the stone less force is applied on it when velocity is constant.

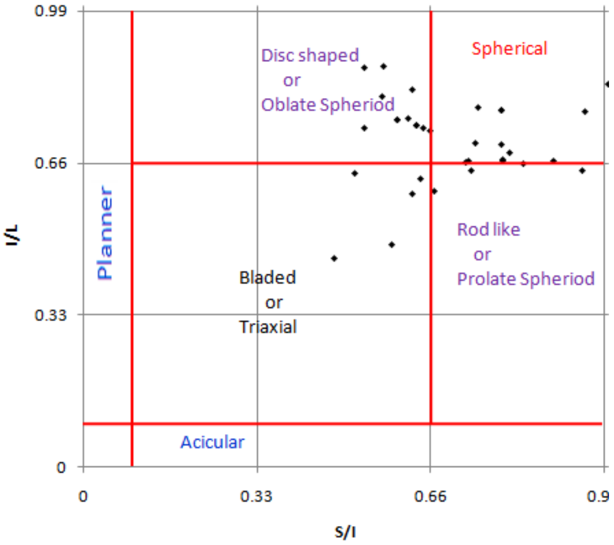

Fig. 8 Classification of the largest stones according to their sphericity (After Zingg, 1935)

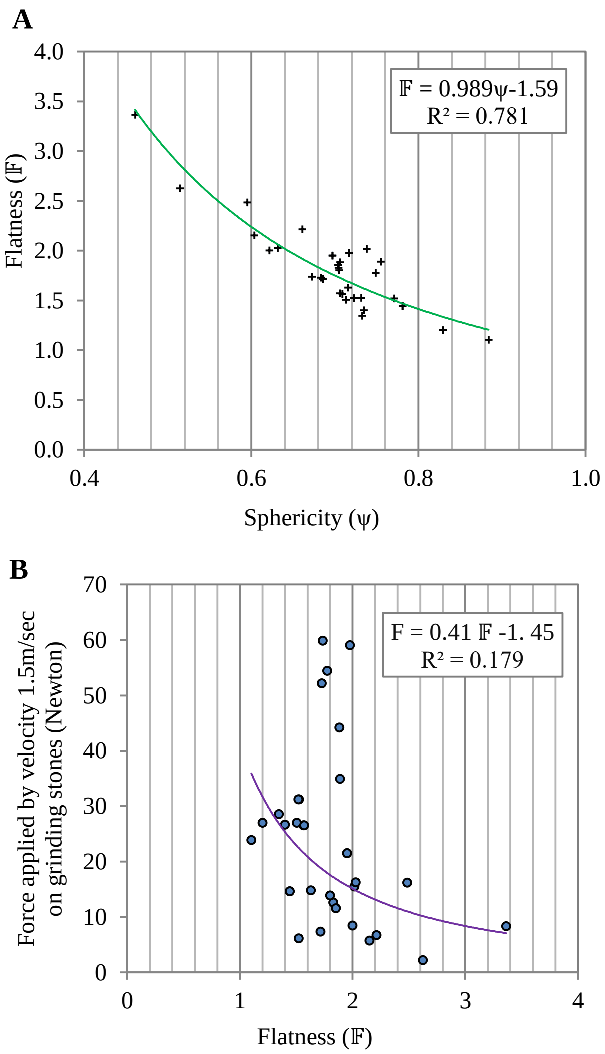

Fig. 9 Relationship between sphericity and flatness of grinding stones (A), relationship between flatness and the applied force by velocity (B)

Controls on stones shape

It was found that with increasing depth/radius ratio (γ) of pothole, sphericity of stones increased. It means that potholes with more depth were associated with more smoother or spherical stones. It happened because episodically entrained stones entrapped in potholes abrade atop floors years after years to increase γ . As a result gradually they became spherical. But bottom shear stress (τ_b) decreased rapidly beyond depth/radius ratio $\gamma \sim 2$. Stones size and shape control amount of force (F) to be applied on them by moving water. It was found that larger the grinding stone more was the force applied on it ($R^2 = 0.98$) and vice versa (Fig. 10A). Forces applied on stones are proportional to sphericity (ψ) and expressed in power relation as $F = 0.59\psi^{3.25}$. On the contrary, higher the flatness lower was the forces applied on stones (Fig. 10B).

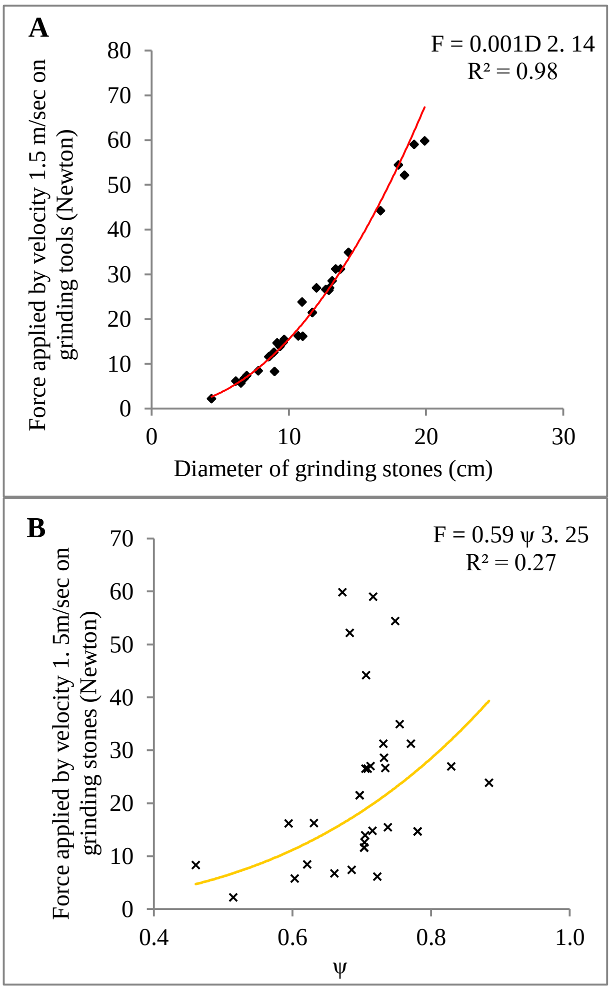

Fig. 10 Relationship between the force applied on a grinding stones and (A) size and (B) sphericity

Flow depth is also important for the process of abrasion work by stones and growth of a pothole and shapes of stones itself. With given channel slope (e.g.~ 10^{-1} m/m) flow depth required for the growth of a pothole is approximately equal to the diameter of the pothole (Pelletier et al., 2014). Data for this study were collected from 34 potholes not within bed of the river in true sense but atop a wide doleritic dyke (well above the river bed). That is why, frequency of necessary flow depth for pothole growth is annual when the dyke is over topped by the peak flow of rainy season. Moreover, Galudih barrage (completed in 1954) at 12.9 km upstream diverts a considerable share of the flow through irrigation canal. As a result discharge can not overflow onto normally dry doleritic dyke and stones in potholes remains idle for years to gather moss on them (Fig. 6D).

The largest grinding stone and potholes growth

The R^2 between potholes size and stones size was much less (0.17) than R^2 between potholes size and stones weight (0.25). Yet, larger the pothole, larger and heavier was the largest grinding stone (Fig. 11). But present study does not confirm the finding of Pelletier et al. (2014) that 'pothole depths increase in proportion to the diameter of the largest clasts episodically stored in potholes'.

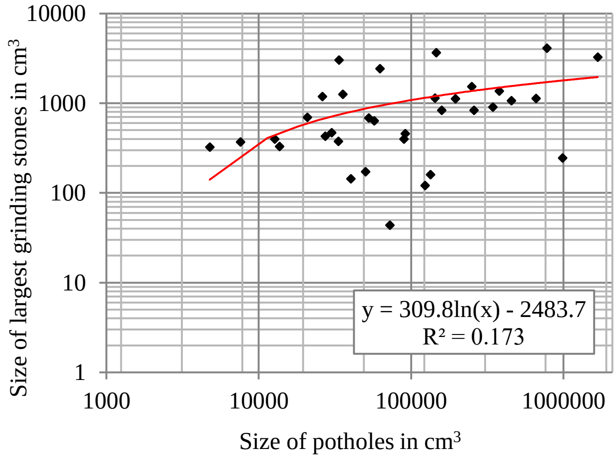

Fig. 11 Relationship between diameter of largest grinding stone and the size of potholes

Absence of convex floor in all potholes indicate the active role of largest grinding stone which abrade atop floor instead of protecting it. So sufficient eddy velocity was there to entrain the largest stones and abrade atop potholes floor. Considering stream velocity 1.5m^{-s} needed for entrainment of the grinding stone of diameter 19.89cm (largest among 34 stones), forces applied on grinding stones were calculated using equation (3). Average force applied on stone was 23.02 N (Newtons) with SD 15.65 avd CV 67.96%. Low variation in ψ and higher variation in applied force indicate that size of the largest stone is not proportional to pothole depths.

CONCLUSION

Grinding stones in potholes are important component of channel incision, as the largest grinding stone has significant control on pothole growth. Largest grinding stone made all the pothole floors concave by abrading atop it. The largest grinders found in potholes cluster of same locality were of same composition which was expressed in strong correlation between stone's size and weight. Diversion of flow by artificial efforts reduced discharge through channel and interfered adversely the natural fluvial environment. Grinding stones in potholes were left idle and mosses gathered on those unrolling stones. Very few grinding stones in potholes are spherical in shape. Drag force applied on the largest grinding stone and their entrainment velocity depends considerably upon their shapes. Therefore, to have an insight into the hydraulics and processes operating within potholes, size and shape of largest grinding stone may be considered as an instrument. This new insight into pothole dynamics will enable better understanding process-form feedbacks in bedrock channel.

Acknowledgement

I deeply acknowledge my gratitude to my students of M.Sc. 3rd Semester with special paper Fluvial Geomorphology (session 2014-16) who did laborious job of data collection on pothole stones.

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JOURNAL OF ENVIRONMENTAL GEOGRAPHY
Journal of Environmental Geography 11 (1–2), 17–26.
DOI: 10.2478/jengeo-2018-0003
ISSN: 2060-467X

EVERY START IS CHALLENGING: FITTING A NEW ARTIFICIAL LAKE INTO THE LANDSCAPE, ZALAKAROS, HUNGARY

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Research article, received 10 March 2018, accepted 22 March 2018

Abstract

The aim of this study is to conclude the experiences of the maintenance practice of an artificial thermal lake. The first years (2015-2017) of the development of the lake were analysed and evaluated along the following questions: a) What kind of design processes and maintenance interventions are related to the process of fitting the lake into the landscape? b) How have the ecological conditions of the lake evolved in the past period (zonation, succession, plantation and colonization)? c) Which general experiences could be gained from the operation of this artificial thermal lake this far? The authors of the present study were already engaged in the planning process, participating in the preparation of four different design documentations. The planting design and the maintenance instructions were based on a physico-chemical monitoring, phytoplankton, zooplankton and macroinvertebrate sampling, and machrophyte assessment. The significant processes during the three years of the lake are presented by functional groups of biota, separately assessing the characteristics of the changes of macrophytes. In 2017 an individual macroinvertebrate assessment was done, moreover a fish die-off occurred in August 2017, which are mentioned separately as well. The data in total suggested that the water of the lake is highly hypertrophic, further machrophyte introduction can prevent the plant nutriments to be absorbed by algae. Partly the algal growth but also the unlucky coincidence of other factors (e.g. high water temperature, cold weather front, maintenance problems) led to the die-off of the spontaneously overpopulated fish stock in 2017.

Keywords: lake management, lake maintenance, thermal lake, algal bloom, macrophyte, succession, fish die-off, Zalakaros

INTRODUCTION

There are several reasons to create artificial lakes, including flood protection, providing water for irrigation and drinking, fish farming, and by opencast mining a plenty of new lakes appear in the landscape as well. Aquifers and quarry ponds – irrespectively of their primary function –become areas of touristic-recreational development in many cases, moreover they are popular leisure time destinations for locals since their formation (Dávid and Német, 2005; Furgala-Selezniow et al., 2012). Due to the rapid succession of water-related habitats and the intense, diverse demand of utilization, the ecological conditions and the environment of the new lakes change at a quick pace (Hall and Härkönen, 2006). In the interest of landscape sustainability (Musacchio, 2013; Wu, 2011) and the protection and improvement of the ecosystem services of the lake and the lake-shore (Vinkó et al. 2012), changes must be carefully arranged (Boromisza et al., 2015; Illyés et al., 2016). In the course of this, it is equally required to mitigate the probable environmental impacts, to ecologically fit the new landscape feature (lake) into the landscape, to serve the needs of the society (Moss, 2007), to discover the natural values and to schedule the maintenance tasks (Mészáros, 2016). The tools and measures of fitting a new lake into the landscape are similar to lake restoration methods (Annadotter et al., 1999; Bain et al., 2000; Cooke et al., 2005; Estrada et al., 2011; Gulati et al., 2008, Ostendorp et al., 1995; Sondergaard et al., 2008)

In Zalakaros (Hungary) a complex touristic-recreational investment was planned, which aimed to create new facilities for leisure activities beyond the existing thermal bath. A visitor centre, a promenade, a colonnade, a fountain, an artificial lake with an island and bridges, a tale park, a labyrinth, a water obstacle course, a parking, meditation space of the lights, seniors' active recreation park, and a nature trail were among the planned elements. The peculiarity of the lake is its water quality, as it is filled with the drain-off water of the thermal bath.

After creating a new lake, it requires several years for the water ecosystem to evolve (Straskraba, 1994), and might be surprising, especially in case of a thermal lake. Fitting a new landscape element into the landscape is a functional, ecological and aesthetical challenge, which can be actually realised through several designs and numerous interventions. The authors of the present study were already engaged in the planning process, participating in the preparation of four different design documentations. The aim of this study is to conclude the experinces of the maintanence practice of the last three years of an artificial lake. Therefore, in our study the first three years (2015-2017) of the development of the lake were analysed and evaluated, along the following questions:

a) What kind of design processes and maintenance interventions are related to the process of fitting the lake into the landscape?
b) How have the ecological conditions of the lake evolved in the past period (zonation, succession, plantation and colonization)?
c) Which general experiences could be gained from the operation of this artificial thermal lake this far?

STUDY AREA

The study area and the thermal lake is located in Western Hungary, at the administrative area of Zalakaros town. There are closed forests on the eastern side of the lake, and gallery forests on the south (Fig. 1). The surface area of the artificial lake is 12900 m^2, its average water depth is 1.5 m (with a shallow cover of 0.4 m at a part of the lake bed around the "flagstones"), its maximum depth is 1.8 m, its volume is 19000 m^3. The length of the shoreline is 484 m, the shoreline development index is 1.2 without the island, and 1.41 including the island. The lake is isolated; its water supply is ensured by using the drain-off of the thermal water ((in other words: used bathing water). The daily amount of the bath's excess water is 600-800 m^3. The average detention time in the lake is approximately 30 days. The banks' average bend is 1:2, and are covered by crushed limestone which unfavourably limits the vegetation growth. The lake is functioning as a "park lake", providing aesthetical value to the city. It is prohibited to use this lake for bathing and swimming it serves only spectacular purposes and not further balneological ones.

METHODS

The planting design and the maintenance instructions were based on a physico-chemical monitoring (concluded between 2015 and 2017, on average once a month, based on own samplings and data retrievals of the lake's operator: surface water sampling considering the Hungarian standards MSZ 12750-2:1971, MSZ ISO 5667-1:2007, MSZ ISO 5667-4:1995, MSZ ISO 5667-6:1995). There was a regular sampling in order to analyse phytoplankton (between 2015 and 2017, four times a year, between April and August): the water samples were condensed on a filter, and their qualitative examinations were made under microscope in order to determine the dominant species in the phytoplankton. There were difficulties to filter the sample on the usual 0.45 micrometre pore size filter plate, thus the second occasion 3 micrometres pore size filter plate was applied. Parts of the condensed samples were examined in different enlargements. At the same time of phytoplankton sampling zooplankton was also sampled by using plankton net with 150 micrometre of pore size. Almost 70 l water was filtered through plankton net on site, and the material remained in the sample container of the net was examined under microscope. The dominant species were determined in the sample. The analysis of macrophytes (qualitative characterization, recording the alteration tendencies of certain species) were done twice a year between 2015 and 2017, between April and September. The sampling of the macroinvertebrates took place in September 2017 with net techniques, at four points of the lake, identifying the individuals in place and valuing their prevalence.

The main danger in this lake is the planktonic eutrophication because the algae can prohibit the growth of the macophytes planted in the lake. That is why chlorophyl-a concentration was a dominant water quality parameter that was also measured several times in a year in an accredited laboratory. According to the OECD scales (OECD, 1982) if the chlorophyl-a yearly maximum concentration is between 2.5-8 mg/m^3 than the lake is oligotrophic. 8-25 mg/m^3 is the mesotrophic range, 25-75 mg/m^3 is the eutrophic one and >75 mg/m^3 is the hypertrophic limit. The hypertrophic status can be dangerous for macrophytes and aerobe heterotrophic organisms living in the lake. The high primary production of the phytoplankton can cause very high oxygen level in daytime but oxygen depletion and fish kills in early morning.

Fig. 1 Location of the study area

RESULTS

Evaluating the fitting into the landscape and the lake maintenance

The maintenance decisions regarding the lake are primarily based on the maintenance plan of the lake and it is implemented through numerous – partly continuously or cyclically occurring – interventions (Table 1).

The first challenge appeared before the construction of the new thermal lake's bed: the forest where the lake was going to be constructed was a habitat of protected species: spring snowflake (*Leucojum vernum)* and white hellebore (*Veratrum album*). To solve the problem the habitat map of the protected plant species in 2013 was prepared and a botanical analysis of the transplantation site and the area of the new lake was carried out. The adequacy of the transplantation site was analysed and a recommendation about the transplantation of the protected species was presented. Unfortunately, there has been no monitoring activities going on about the success of the transplantation since it happened, however, based on the experiences of regular field surveys it is obvious that high number of individual plants of both species can be found in the transplantation area. The interpretation and introduction of natural values to visitors were defined as a goal in the transplantation area of the protected species: the next step of the design process was to design a nature trail constructed of plank in 2015. The design and the realization of the nature trail required not only technical work, but also to prepare complex, high quality, unique graphical materials based on ecological and pedagogic knowledge. Thus it became a holistic process, the foundation of creating facilities which provide adventurous and attitude-changing experiences.

Once it was possible to form and fill the new bed, the next design challenge was to accomplish the plantation of the lake – thus contributing to the landscape fitting ecologically as well. Besides their aesthetical and habitat significance (providing hiding-place, foraging space, nesting site and spawning ground to several animal species), aquatic and riparian plants have a striking role in the design area from the aspect of water quality: by their nutrient uptake and shading, they can limit the unfavourable excess growth of algae, moreover the oxygen production of some submersed species is notable in the water as well (Brown et al. 1974; Maberly and Spence, 1989; Scheffer, 2004; Szilágyi, 2001). To prevent the dominance of algae, at least 30-40% of the water surface has to be covered by macrophytes (higher order aquatic and riparian plants) (Brown et al. 1974), which might take several years. Consequently, the primary role of the recommended planting design was to contribute to the conservation of the water quality, to create ornamental plant cover on the water surface and to form aesthetical focal points on the lake.

The method of planting was significantly influenced by the realized construction works and its structure: the formation and isolation of the bed, its bottom and the formation of the banks. The fact that no planting medium and reed berm were created is a determining factor (thus in the case of the banks, a different planting method had to be applied.) In the course of choosing the species and creating the spatial arrangements the lake's natural aptitudes defined the basic criteria: the peculiarity of water quality, exposure to undulation, the morphological aptitudes of the lake – its depth conditions, temperature conditions and solar access. Considering the above aspects, 6 riparian (1446 specimens), 4 floating leaf (248 specimens) and 2 submersed aquatic species (20 specimens) were included on the species list.

While carrying out the different planting methods, adequate timing and setting water level needed for construction works were of high importance. The water had to be let down before planting the aquatic plants. The floating leaf *Nymphaea* species were placed at 1 pcs/3m^2 density, in water planting baskets lined with linen sacks. Considering the depth of the lake, the baskets of younger *Nymphaea* plants were not directly placed on the bottom but raised by brick columns.

Table 1 Overview of the design process and management interventions related to the lake

Design	Time	Construction, intervention, arrangements	Time
Transplantation plan of the protected plants	September 2013	transplantation	October 2013
Planting design of the lake	March 2015	plantation of riparian and aquatic plants	July-August 2015
Nature trail design	November 2015	nature trail	December 2015
Maintenance plan of the lake	April 2016	phyisico-chemical monitoring	2015-2017
		phytoplankton and zooplankton analysis	2015-2017
		macrophyte assessment	2015-2017
		macrophyte replacement	October 2016
		macroinvertebrate assessment	September 2017
		vinegar weed control on banks	April-September 2017
		filamentous green algae removal	April-September 2017
		macrophyte cut-back	October-November 2015-2017
		application of bleaching powder	August 2017

The submersed species also had to be planted directly to the bottom, in a density of 3 pcs/m^2. Planting on the banks protected by rip-rap demanded an untraditional procedure as well. Proper quality rhizomes had to be collected of riparian plants (mostly: *Typha angustifolia*) (Hawke and José, 2002; Henderson et al. 1999; Robinson, 2006) that were surfaced from canal dredging in the region. The rhizomes wrapped in jute sacks had to be fixed between the bank's rocks, 30-50 cm under the operating water level. The riparian plants in the shallow area were distributed at operating water level, at an average stem distance of 50 cm, placing the planting baskets directly on the bottom (Fig. 2).

The maintenance plan of the lake was completed in April 2015, then for the request of the local government it was modified in April 2016 and revised in November 2017. The different monitoring activities and condition analyses were constant maintenance tasks. Certain factors were only analysed occasionally (e.g. the macroinvertebrate assessment was carried out only once in September 2017). Part of the maintenance tasks were previously known, planned and scheduled (e.g. the winter cut-back of macrophytes), while others required individual decisions and quick reactions based on the actual water quality (e.g. application of bleaching powder).

Phyisico-chemical water quality

The first analysis results related to the lake were the abiotic factors. Concluding the data acquired between 2015 and 2017 it was found that the chemical water quality of the lake was characterized by high salinity, relatively high pH, low concentration of plant nutrients, that can be uptaken by algae and low organic matter content. The chemical characteristics of the lake were determined by the water quality of the supply wells, moreover – due to the long detention time – they softened the alterations definitely present in the operation of the bath, thus the changes of the water quality were not significant and slow. The lake was fed by the used thermal water of wells filtered at 1200 m and 2000 m deep, and rainwater.

Analysing the data of 2017 more in details, the following were ascertained (the results of our own samplings are shown in the Table 2). The typical transparency/Secchi depth of the water was 50-75 cm. Regarding the medium depth this means that the light was not able to reach the surface of the sediment constantly on all sites, impeding benthic photosynthesis. Considering that the water of the lake did not constantly contain excess algae, the inorganic colloidal materials, which got to the water through the sediment or could be developed throughout chemical precipitation in the lake, were highly responsible for the low transparency. In total their shade was beneficial as during periods with excess algae benthic photosynthesis was not favourable.

Amongst the plant nutrients, the concentration of the absorbable nitrogen forms was constantly low according to the samplings: the concentration of nitrite and nitrate was usually under the measuring range, and the concentration of ammonium was low as well, not contributing to algae growth. The concentration of phosphorous forms was similarly low, under the measuring range. In the water of the bath the concentration of these nutrients was very low, those that were still present were immediately absorbed by the algae in the lake. As per our opinion, the main nutrient sources were primarily the sand layer covering the lake, secondary the atmospheric drift (dust).

Fig. 2 Formation of the lake bed and the planned macrophyte plantings at the shallow area of the lake (near the "flagstones")

*Table 2 Char*acteristics of physico-chemical water quality, based on the samplings carried out in 2017

Component	15 August 2017	30 August 2017	14 September 2017
Flagstones			
pH	8.74	9.56	8.27
Conductivity (µS/cm)	3860	3860	3620
Dissolved oxygen (mg/l)	12.68	20.02	11.50
Oxygen saturation (%)	154.4	266	127.7
Water temperature (°C)	24.8	29.1	29.3
Arched bridge			
pH	9.56	9.43	8.71
Conductivity (µS/cm))	3840	3840	3800
Dissolved oxygen (mg/l)	21.38	19.82	8.39
Oxygen saturation (%)	266.7	260	95.5
Water temperature (°C)	25.9	28.4	20.6

The chemical oxygen demand of the water was usually low – as it is typical in the case of a water beforehand used for bathing. The high COD values were related to the high algae concentration. In case of the highest a-chlorophyll concentration COD values were close to the values of purified sewage, although it was caused by the high algae organic matter content, which is particularly unfavourable. Salt content is also mentionable (conductivity), including the chloride concentration. It was noticeable that the approximately 2200 µS/cm conductivity measured in winter and spring increased above 3000 µS/cm by the summer, beside a chloride concentration of approximately 1000 mg/l. At the end of August conductivity was stably above 3800 µS/cm, and chloride concentration increased above 1440 mg/l as well. This alteration could be caused by three reasons: (1) The bath availed itself more of the deeper well with higher salinity; (2) The unusually hot summer (with 56 record hot days that year) resulted in the concentration of the lake's water; (3) The input pump was broken for a long time, and the lake received fresh water only through a low performance supplementary pump, which contributed to the concentration of soluble ions including chloride.

At both sampling points the conductivity of the water was high, and similar to each other. At the area around the flagstones the water supply came from the same source as the water supply of the lake, thus there was no possibility for a significant difference. The temperature of the water was 1.1°C colder than at the bridge. Around the steps oxygen supersaturation was observed in the water which is the result of the significant photosynthetic activity. This could be the result of the oxygen production of the phytoplankton and *Cladophora sp*. Though this supersaturation was significant, it would not have required intervention itself. Exceptionally significant oxygen supersaturation was observed in the water around the bridge which was the result of the very high photosynthetic activity of the phytoplankton. The oxygen production was so strong that the produced gas bubbled out of the water. Due to the strong photosynthetic activity the pH became highly alkaline. The data in total suggested that the water of the lake is highly hypertrophic, which was indicated by the greenish-brownish colour of the water as well. It is necessary to avoid the hypertrophic conditions in the lake because the valuable planted macrophyte vegetation can loose the competition for light and plant nutrients against phytoplankton.

Changes of biota

The main goal of fitting the lake into the landscape and the maintenance of the lake was to reach a favourable ecological condition, which was the base of the aesthetical value and the utilization of the lake as well. The significant processes during the three years of the lake were presented by functional groups, separately assessing the characteristics of the changes of macrophytes (Table 3). In 2017 an individual macroinvertebrate assessment was done, moreover a fish die-off occurred in August 2017, which are mentioned separately as well.

As riparian / aquatic plants significantly influenced the ecological condition and the view of the lake, and there was a designed plantation as well, we analysed the situation of macrophytes in detail. The plantation of the lake was not completely assessable, the spectacular fluctuation of the water ecosystem could be expected for years (certain planted species lost ground, others appeared spontaneously) (Table 4). Based on observations done until now, yellow iris *(Iris pseudachorus)* has been the most successful amongst the planted riparian plants. The spectacular late vernal bloom of the robust plants and the 100% remaining rate is a clear sign of its appropriateness. Only a few stems of the flowering rush *(Butomus umbellatus)* planting did not survive, therefore, these plants created a unified patch as well. Dwarf bulrush (*Typha minima*) has been planted in high numbers near the water obstacle course. The observations were ambivalent related to this species. Plants completely perished on the south of the shallow bay, outside the flagstones, however the western side of the same patch was especially aesthetic, almost complete and in good health condition. Plants planted on the north-west of the area showed a transitional image, here the stand was strongly scanty and imperfect (approximately 100 pcs remained of 192 pcs). In total, approximately 240 pcs of the planned 432 remained.

Table 3 Changes of wildlife between 2015-2017

	2015	2016	2017
phytoplankton	In May diatoms were dominating, especially *Navicula* speciescwere characteristic. Filamentous green algae *(Cladophora sp.)* were also observed in different quantities. The bottom of the lakebed was covered by filamentous cyanobacteria. Nitrogen fixing cyanobacteria became characteristic. In the first year of the operation scanty phytoplankton was characteristic of the lake, and the size of algae was also smaller than usual. We assume that the aftereffect of the disinfectant applied in the bath had impacted the lake's phytoplankton.	A few living diatoms (especially *Navicula sp*., and *Nitzschia sp* species) were present in May, and unicellular and thallophyte green algae were characteristic as well. Filamentous green algae (*Chladophora sp*.) developed massive amounts by the middle of the summer.	In the summer of the third year, algae (especially *Euglenophytas*) proliferated in a huge mass. In August 2017 200mg/m^3 a-chlorophyll values were measured. Part of the oxygen produced during the photosynthesis bubbled out of the water. There were few species with extremely high individuals in the samples. Nitrogen fixing cyanobacteria were subdominant (especially *Anabaenopsis sp.)*, besides *Synechococcus sp*., *Gomphosphaeria sp*. and *Croococcus sp*. cyanobacteria were also found. Filamentous green algae (*Cladophora sp.)* were also observable primarily in smaller patches.
macrophytes	A planned plantation was done. In some shore segments a spontaneously spreading, warm-season monocotyledonous weed, barnyard grass (*Echinochloa crus-galli*) appeared in large quantities. Besides the plantation some species started to spread spontaneously in the lake.	From the planted vegetation, populations of water lilies (*Nymphea sp*.), yellow iris (*Iris pseudachorus*) and flowering rush (*Botomus umbellatus*) remained almost completely. In the case of great manna grass (*Glyceria maxima*) the rate of extinction was approximately 30%, in the case of dwarf bulrush (*Typha minima*) approximately 50%, in the case of fringed water lily (*Nymphoides peltata*) approximately 80%. A few stems of lesser bulrush (*Typha angustifolia*), the first completely spontaneously growing riparian plants appeared in the shallow water.	Extensive patches of submersed aquatic plants (Eurasian watermilfoil - *Myriophyllum spicatum*) fixed to the bottom were observable. The significant spreading was noticeable since spring.
zooplankton	The lake's zooplankton was very scanty throughout the three years, the number of species as well as the biomass were remarkably low. Protozoa and rotifers were dominating.	The lake's zooplankton was very scanty as well, with the domination of filtering organisms (*Daphnia sp*., rotifers), predator zooplankton organisms were rarely found.	Ciliate protozoa were present in small number, rotifers were rarely found. Usually the species structure of the zooplankton was scanty, its biomass was low.
macroinvertebrates	The first water bugs appeared, the several exuviae of adder-flies *(Odonata)* were extremely noticeable on the stems of riparian plants. In general the number of macroinvertebrate species and their biomass were low.	Several exuviae of adder-flies *(Odonata)* can be found on the stems of riparian plants like in the previous year. In the shallow water area larvae of mosquitos were not observable, however bloodworm larvae were found in one of the sludge samples.	This functional group is scanty in general, representatives of many groups were missing completely. However the high number of dipterous larvae individuals is remarkable.
vertebrates	There was amphibian spawning in the first spring after the filling.	Adult fish were observed: common bleak (*Alburnus alburnus*) individuals lived in the lake. Several tadpoles and adult frogs belonging to different species were found near the shoreline. The appearance of a reptile species, the grass snake (*Natrix natrix*) is a new finding.	A red-eared slider (*Trachemys scripta elegans*) were also seen during the fieldwork. Fish were never introduced to the lake, in spite of this a fish population evolved. A mass fish die-off occurred killing 1,1t fish, especially common bleak (*Alburnus alburnus*) and silver prussian carp (*Carassius auratus gibelio*).

The great manna grass *(Gliceria maxima)* patch was slightly imperfect in 2016 as well. Only narrow-leaved cattail (*Typha angustifolia*) gave off shoots amongst the plants planted along the north shoreline. These were present on the shoreline in front of the "meditation space of the lights", on both sides of the bridge, creating a continuous belt in visibly good health condition. By 2017 a significant expansion was observable of this species. On one hand, it reached the lake at the original plantation, on the other hand a spontaneous growth appeared in the obstacle course area. Planted common read did not give off shoots, as it was planted by rhizome in the middle of July which is a not suitable period for planting reed. It was not inevitably necessary to replant this species.

Water lilies *(Nymphea sp.)* were basically planted in three patches and they are the most outstanding eyemark of the lake. Visibly they were in good health condition, and their continuous bloom also suggested that they found favourable conditions. Especially the varieties with yellow flower were healthy. Unfortunately, they were not expanding with adequate speed which might be caused by the algae growth. In the competition for light and nutrients between algae and seaweed, currently algae are in better position as the adequate macrophyte cover (30-40%) has not yet developed in the lake.

Unfortunately, the other floating leaf species planted near the water obstacle course, fringed water lily (*Nymphoides peltata)* population suffered more, right now only a few stems could be discovered from the original planting. The assumable reason for the significant die-off is the unfavourable effect of the filamentous green algae (*Cladophora sp.)* on the young fringed water lily individuals in 2016. Floating seaweed hornwort (*Ceratophyllum sp*.) did not remain in the lake either, currently it is not visible.

In 2016 Eurasian watermilfoil *(Myriophyllum spicatum)* individuals were only visible in some areas, along the lake's south shoreline. In 2017 this species spontaneously proliferated almost everywhere along the shoreline and near the obstacle course as well. In May 2016 barnyard grass *(Echinochloa crus-galli)* was visible in places along the shoreline – due to maintenance these have already disappeared. The town management company carried out a smaller complement plantation on the lake in October 2016. 80 pcs of flowering rush *(Butomus umbellatus*, 70 pcs of dwarf bulrush *(Typha minima)* and 30 pcs of variegated reed sweet-grass (*Glyceria maxima „Variegata"*) were planted in order to complement the scanty vegetation.

The aquatic macroinvertebrates indicate well the quality of the habitat, many organisms that can be used as indicators belong here. The autumn of 2017 was critical in terms of water quality therefore an assessment was done focusing especially on this group of organisms. 14 taxons were present in the thermal lake in total (Table 5). Only the empty carapaces of a mollusc species were detected in the water which indicates the still perceptible effects of the recent fish die-off (see under). Curiously, many groups of invertebrates were completely missing: vermicules including leeches, mussels and snails, as well as crabs. Above all, it was also ascertainable at the first sight that only adder-flies, true water bugs and diptera are present in the water. The most numerous group consisted of bloodworm and small true water bugs (*Micronecta sp., Plea leachi*). Amongst adder-flies only three common species were detectable in the water. The most populated group was observed in the common area of the emersed and submersed aquatic plant stands, as here the most diverse microhabitat patterns could develop. The several recently leaved adder-fly exuviae on the stems of the narrow-leaved cattail (*Typha angustifolia)* standing in water indicates that this type of environment offers an excellent habitat for these animals.

It is ascertainable that the most diverse group consisted of true water bugs, as 8 from the discovered 14 taxons belonged here. However, regarding the population size diptera was the most numerous in the invertebrate group. In general, the organism group was scanty, species of many groups were completely missing, due to the unfavourable trend of water quality. On the other hand, the high number of dipterous larvae individuals stabilised in the lake was noteworthy. Probably the reason for this is that the threat of the scarcity of direct dissolved oxygen has significantly decreased. Although a regular oxygen supersaturation typical of hypertrophy occurs daily in the lake, probably oxygen is not consumed completely, as these creatures does not utilize atmospheric oxygen like true water bugs, but dissolved oxygen instead. This can be connected to

Table 4 Alteration tendency of macrophyte species

Macrophyte species	**Plantation method**	**Alteration tendency**	
Typha angustifolia	by rhizome	expansive	
Typha minima	by planting basket	decreasing	
Phragmites australis	by rhizome	didn't take root	-
Glyceria maxima	by planting basket	decreasing	
Iris pseudachorus	by planting basket	stable	
Botomus umbellatus	by planting basket	stable	
Nymphaea sp.	by planting basket	stable	
Nymphoides peltata	by planting basket	decreasing	
Myriophyllum spicatum	by planting basket	increasing	

their mass presence and the recent lack of significant fish population in the lake that could decrease the number of these animals by overgrazing.

Table 5 Macroinvertebrate taxons found in the samplings in 2017

Taxon	Sampling points				
	1	2	3	4	Σ
Physella acuta			12		12
Ischnura elegans pontica	19	11	6	17	53
Anax imperator	12	9		3	24
Orthetrum cancellatum	2	1	5	3	11
Plea minutissima	67	12	22	10	111
Callicorixa praeusta	1				1
Corixinae Gen. sp.			2		2
Gerris sp. Juv.				1	1
Hesperocorixa linnaei		1			1
Hesperocorixa sp.		3			3
Micronecta sp.	36	5	12	8	61
Sigara sp.			1		1
Chironomidae Gen. sp.	122	69	13	45	249
Stratyomyidae Gen. Sp.	3			1	4
Individual number in total	**262**	**111**	**61**	**88**	**522**

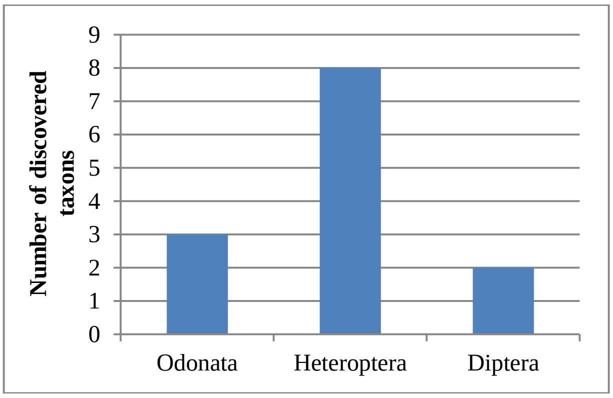

Fig. 3 Number of the discovered taxons/species in the three insect groups

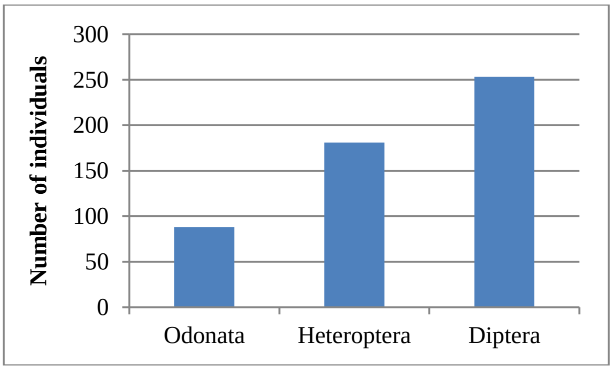

Fig. 4 Number of individuals in the three insect groups

Mass fish die-off occurred in the lake on 29 August 2017. It the phenomena more curious that there was no conscious fish introduction in the past three years, furthermore the lake bed was not connected to any natural surface water. The presence of fish was first observed in spring of 2016, and was also confirmed by a midsummer trial fishing in 2017. The die-off is significant in respect of lake maintenance and requires an extensive analysis. The several reasons for the perishing of approximately 1.1 t fish are concluded here:

- Prior the fish die-off filamentous green algae and nitrogen fixing cyanobacteria had proliferated significantly in the lake. As a result, an oxygen supersaturation had developed by the early afternoon, and part of the oxygen had bubbled out of the water. Algae produces net oxygen during the day, but consumes oxygen at night, as they breathe as heterotrophic creatures in the water. On 29 August by dawn oxygen scarcity occurred which eradicated most (if not all) of the fish stock.
- The heat experienced many times in August, with an average daily temperature above 25°C had contributed to the algae growth by causing the warming up the of the lake's water. The solubility of the oxygen is inversely proportional to the water temperature, at the same time the oxygen consumption of heterotrophic creatures is directly proportional to it. Consequently, the oxygen produced during the day had been consumed quickly at night (oxygen concentration under 3 mg/l is a danger to the fish stock). Hypoxia was indicated by the aquatic surface respiration of fish.
- Chlorine tolerance of algae was low, most of them perished by 0.3-0.5 mg/l active chlorine. Bleaching powder was not applied when it was recommended by the authors of the present study (19 August 2017), prior to the fish die-off. This could have slowed down the algae growth and could have decreased the oxygen consumption of the bacteria as well.
- In the case of usual water supply the active chlorine present in the input water could have kept in check the phytoplankton. Unfortunately, approximately two weeks before the end of August the input pump broke and only a low performance pump pumped the water to the lake. As a result, neither fresh water nor active chlorine were adequately supplemented and the phytoplankton association overgrew. The minimum one-month long average detention time was enough for this to occur.
- A strong cold front reached Western Hungary by 29 August. Living beings are also affected by fronts. According to an old observation, in case of certain type of fronts hypoxia occurs in lakes (especially in fishponds) at dawn, and if there is no possibility for artificial aeration the third or half of the stock perish. The same kind of cold front arrived at the end of August. It only reached Western Hungary and passed from south to north.

Fish die-off occurred in many fishponds and lakes at the same time, for example tons of fish died in the lake Kis-Balaton. Accordingly, the fish die-off at Zalakaros was not only a local phenomenon. However, it could have been prevented (by applying bleaching powder and installing higher performance input pumps at the appearance of the expansive algae population).

- The lake was strongly overpopulated by fish, few species were present in high individual numbers. This was partly responsible for the perishing of the zooplankton and the macroinvertebrate organisms. We did not assume that without introduction such a large biomass of fish could develop in the lake in three years.
- Probably most of the fish perished already on the 29 August, although most of the carcasses sank to the bottom. These only came up after a few days, as a result of the decomposition gases produced by the dead bodies. That is why aquatic surface respiration of fish was not observed in the next days.

CONCLUSIONS

Zalakaros town is well-known due to its thermal bath offering significant therapic value for many people, however, it lacks other free-time activities. This is compensated by the recently created artificial thermal lake, being under investigation in this study, due to its high aesthetical value and the connected recreational facilities. The artificial lake was a major challenge for the landscape architect as well as for the water quality specialist, as there were few experiences related to similar lakes. The unique characteristics of the lake are the high salinity, the significant concentration of well soluble salts, the low concentration of organic matter and plant nutriments, and the higher water temperature compared to other water-bodies of the nearby area. In the first years of operation the ecological tilting/sways caused extra work for both the maintenance and the consulting experts. As the new lake itself is an artificial-like element with ruined surfaces it was a fundamental aspect for us to naturalize it and to improve the diversity of habitats. The maintenance of the water quality and ecological condition requires regular and professional lake maintenance work, including the important tasks of operating the monitoring and treating the atypical phenomena.

The newly created aquatic ecosystems can frequently change dramatically year to year (tilting or swaying). This is their normal behavior that can last 5-10 years. Sways are still significant in the ecosystem of the thermal lake of Zalakaros. The massive overpopulation of filamentous green algae in 2016 and filamentous green algae and cyanobacteria in 2017 caused problems. On the other hand, the macroinvertebrate group and the zooplankton had few species and small biomass in the lake. The reason for this requires further analysis. Partly the algal growth but also the unlucky coincidence of other factors led to the die-off of the spontaneously overpopulated fish stock in 2017. This could have been decreased by certain interventions and adequate timing. However, it is probable that in few years the fish population will grow again in the lake, but this process should be regulated by colonizing predator fish in small numbers.

Plantation can prevent the plant nutriments to be absorbed by algae, instead of macrophytes. However, plantation is expensive, and in case adequate macrophyte cover cannot be reached, algae growth can cause serious water quality issues. Keeping the water level low in spring in order for the macrophytes to grow up from the bottom can serve as an alternative solution. In spite of the numerous plants planted in this lake controlling the algae and the macrophytes have not succeed yet, as macrophytes require a long time to spread. Besides the further plantations it is suggested to establish such built elements that enhance the lake's attraction as well as the species and habitat diversity, and habitat complexity in the same time (e.g. man-made bird island, nesting holes).

Acknowledgements

We render thanks for their cooperation to the local government of Zalakaros town, to Karos-Park Városgazdálkodási Kft., to Kertrendező Kft, and to Gránit Gyógyfürdő Zrt for their cooperation.

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JOURNAL OF ENVIRONMENTAL GEOGRAPHY
Journal of Environmental Geography 11 (1–2), 27–36.
DOI: 10.2478/jengeo-2018-0004
ISSN: 2060-467X

ASSESSMENT OF LANDSCAPE CONFLICTS IN MOTORWAY PLANNING, NE HUNGARY

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Research article, received 11 March 2018, accepted 25 April 2018

Abstract

Field surveys are essential in the Hungarian motorway planning process so that it would be possible to assess their impacts on the landscape, since the available databases are insufficient in respect of listing all the valuable elements of the landscape. The aims of the research are to analyse the impacts of the planned M30 Motorway (located in north-eastern Hungary) on the landscape, to enumerate the cultural and natural valuable elements of the landscape near and within the area to be expropriated, to explore the possibilities of their protection and to outline the possible land use conflicts likely to arise after the implementation of the motorway. The main sources used for the research were: landscape, green space management and environmental protection studies made for the modification of the affected settlements' urban plans, field surveys alongside the entire track, and existing environmental databases. In the case of M30 motorway, the chosen corridor was mostly acceptable in the sections where the motorway track leads along the track of the existing Main Road 3, because it is fitted to an existing linear artificial landscape element, it is basically on the border of two natural micro-regions and can also fit into the existing land use structure. Nevertheless, it is not considered to be the best choice in places where it separates vineyards from vine cellars, where it is located within 50 meters from residential areas or where it passes through small plot vineyards or horticultural areas instead of the arable lands of the nearby plain.

Keywords: European Landscape Convention, landscape protection, land use conflicts, planned motorway, ecological barriers

INTRODUCTION

In accordance with the European Landscape Convention – ratified by Hungary in 2007 – the landscape "is an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors". The preamble states that the landscape "contributes to the formation of local cultures and that it is a basic component of the European natural and cultural heritage", it is "an important part of the quality of life for people everywhere" and "landscape is a key element of individual and social well-being and that its protection, management and planning entail rights and responsibilities for everyone". Thus, as a result of the above mentioned citations, landscape policy has to be integrated into any other policies – like transport planning – directly or indirectly impacting the landscape.

Road development has been a necessary task all through mankind's history (Rostovtzeff, 1926), but nowadays these road development demands have increased due to the rapid progress of motorization (Jones, 2008). The establishment of transport connections and the provision of the existing connections' usability are in the whole society's interest, since road transportation has a lot of positive socio-economic effects as well, like increasing employment (by mobilizing manpower), aiding underdeveloped areas to catch up, strengthening urban-rural links (Merriman, 2012). Besides these aspects, road projects also have several negative environmental impacts on the landscape, which are highlighted in the research.

Nowadays technical limitations of road constructions have almost disappeared; roads can be led along completely new tracks almost everywhere in the landscape, without being adapted to the terrain or the hydrographic conditions. Due to the rise of speed limit and increase of traffic, the geometry of the road must be adapted to strict technical standards in order to ensure road safety (Gulyas, 2006; Aarts and Schagen, 2006) resulting in a greater intervention in the landscape: e.g. a 13 m wide two-lane road is less safe than a 16 m wide road (2+1 lanes) with a road separation cable barrier in the case of huge traffic load (Bergh et al., 2016). Moreover, in the case of a motorway the crown width is much wider (even 26.6 m as in the case of the M30 Motorway) and road safety depends e.g. on the width of the emergency lanes or the central median barrier (Bergh et al., 2016; Bramaister, 1999) making the motorway wider. So the environmental impacts of road development can be more significant because of the greater intervention in the landscape than they were before the construction of motorways.

A new road line and its connecting facilities (e.g. drainage ditch, petrol station, rainwater reservoir, new utility lines or just a temporary land use change which can be caused by the construction works) result in direct land use changes and land use structure changes; nevertheless, indirect land use changes often also occur as a result of better regional accessibility after the development of the transport links (Eiter and Potthoff, 2016; Yuchu et al., 2016). In addition to the direct land use changes, the related land uses are limited by the buffer areas of the roads. (Possible uses are regulated by Gov. Decree No. 253 of 1997 in Hungary. It is forbidden to plan built-up areas except for industrial areas along the motorways in a 250 m wide area each side.) Roads not only ensure good accessibility and connection between settlements, but can also be functional barriers for local people (Hawbaker et al., 2006). Furthermore, land use changes can result from the modified hydrological (or other abiotic) conditions which might be caused by the construction of road subgrade – e.g. disappearance of edaphic forest communities, like marshland forests (Fi, 2000). Besides, valuable land use can be endangered by road projects too, like historical land use structure (Ihse, 1995), traditional land uses (Antrop, 2005), unique landscape elements, characteristic plantings – like a line of trees with a special silhouette or a striking visual appearance, and a clump of trees, which can act as landmarks – alongside the road or forests (Liu et al., 2014; Gurrutxaga et al., 2011).

The visibility of the roads and their connecting facilities mainly depends on the category of the road (need of earthworks), the relief, the vegetation and the surrounding buildings, but the perception of visual quality is an interaction between people and their environment (Transportation Research Board of the National Academies, 2013). Visual impacts cannot be defined without interviewing the stakeholders (or without determining frequented viewpoints). Visual changes occur due to the appearance of huge road embankments, bridges, noise walls; or the changes of the vegetation (e.g. disappearing of characteristic alleys). Hungarian planning practice lacks methodology for quantifying or qualifying these visual impacts, but there are some good international examples to be adopted (The Landscape Institute with the Institute of Environmental Management and Assessment, 2002; Transportation Research Board of the National Academies, 2013). The landscape character assessment could also be a great basis for the road projects' visual impact assessments (Boromisza et al., 2011), as in Scotland (Kabai, 2010), where recommendations are offered based on the landscape character assessment concerning various types of interventions in the landscape (like a motorway or other roads) in order to minimize (or avoid) negative visual impacts. However, in Hungary the realization of a landscape character based landscape classification system is currently in progress, and the recommendations are not yet known.

There are also negative impacts on the ecosystem, among which the most important ones are fragmentation and habitat loss (Forman and Alexander, 1998; Trombulak and Frissel, 2000; Bata and Mezősi, 2013). Fragmentation means that the roads are ecological barriers or filters for animal movement, subdivide populations and reduce the size of habitats. One of the results of fragmentation is animal mortality due to collision with vehicles, but the genetic consequences are more significant and dangerous (Forman and Alexander, 1998; Trombulak and Frissel, 2000). Critical habitat reduction occurs when the habitat of insects falls below 1 ha, the habitat of small mammals falls below 10 ha or the habitat of birds falls below 100 ha (Blake and Karr, 1987; Lord and Norton, 1990). The landscape ecological research on the fragmentation of Hungarian natural micro-regions made it clear that the most important ecological barriers are to be found in valleys, in small mountain pools, near Lake Balaton and near Budapest (Csorba, 2005). Another negative ecological impact can be the rapid spread of invasive plant species in the disturbed surfaces – which endangers the naturalness of valuable habitats (Hulme, 2009). Moreover, negative ecological impacts can be caused by the disruption of local hydrological conditions, pollution of local watercourses by road run off, effects of road lightning or noise, effects of air pollution from vehicle emissions or disturbance during construction (Byron et al., 2000). In spite of the numerous negative impacts, areas along the road track are habitats too, where protected species can subsist, e.g. orchids in the roadside or amphibians in drainage facilities (Puky, 1999).

In Hungary, most of the road development projects are financed by the European Union through the Integrated Transport Development Operational Programme in the period between 2014 and 2020. Altogether a HUF 1,040 billion EU fund is allocated, approx. 30.5% of which serves for road development goals (Integrated Transport Development Operational Programme, 2014-2020). One of the road projects to be financed by this Operational Programme is the planned M30 Motorway between Miskolc and Tornyosnémeti, which is our study area. In accordance with Annex 2 of Gov. Decision No. 1247 of 2016 this project is one of the national priority projects. The motorway is currently under construction and is planned to put into operation in 2021 (based on the website of the National Infrastructure Development Corporation). The M30 Motorway is part of the Trans-European Transport Network (TEN-T), namely „Via Carpathia", between Klaipeda–Thessaloniki.

The main aims of the research are to investigate the impacts of the planned M30 Motorway on the landscape, to assess the possible impacts on the valuable cultural and natural elements of the landscape, to explore the possibilities of their protection and to outline the probable land use conflicts that might arise after the implementation of the motorway. Land use conflicts can occur because the proposed developments and land use changes can affect landscape qualities that are valuable for people (Bengston et al., 2004). Land use conflicts are also the result of different perceptions of a group of people about landscapes and their services (Brody et al., 2004). Thus, a land use conflict is a contradiction between two neighbouring land uses – and the groups of people who use the land in different ways: which can cause functional (e.g. disturbance, functional barrier), ecological (e.g. disturbance of valuable habitats, pollution) and visual conflicts.

STUDY AREA

The study area is located in Borsod-Abaúj-Zemplén County, near the north-eastern border of Hungary. The planned motorway is to lead towards Slovakia's second biggest city, Kosice. The examined section is 56 km long and affects 21 settlements (Fig. 1). The study area (see Fig.1) also contains the plots connecting to the expropriation area of the motorway (the main reason for this is that exactly the same delineation was used in the corroborative examinations carried out for the modification of the affected settlements' urban plans).

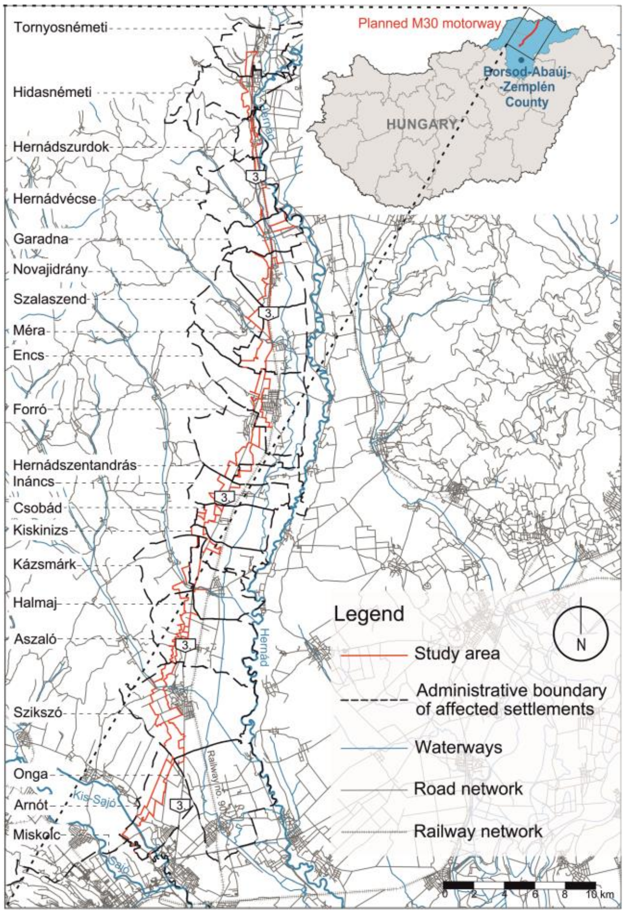


Fig. 1 Location of the study area and the affected settlements

The area studied in details is 3620 ha, of which the territorial distribution per settlement is shown in Fig. 2 (with the length of the planned motorway). Arnót and Szikszó are the two most affected settlements in respect of the territorial distribution and the length of the motorway. The track of the motorway basically leads along the border of Eastern-Cserehát and Hernád-Valley natural micro-regions, and between Arnót and Szikszó the road track affects the Sajó-Hernád plain and the Western-Cserehát natural micro-regions (Marosi and Somogyi, 1990). The elevation is between 110 mBf (near Miskolc) and 200 mBf (near Tornyosnémeti, Aszaló and Szikszó) in the study area. The main soil types on the lower areas are various meadow soils (meadow, meadow chernozem, and meadow alluvial soil). The higher areas are covered by brown forest soils (Ramann's brown forest soil, and chernozem brown forest soil). The climate is moderately warm and dry in the south and moderately cool and dry in the north, meaning that the average annual temperature falls between 9.2-9.6 ºC and the annual rainfall is between 540-640 mm. The prevailing wind direction is northern, north-eastern. Its average speed is 2-2.5 m/s.

The determinative linear landscape elements in the examined regions are the watercourses (especially the Hernád and Kis-Sajó rivers), the Main Road 3, and the Railway Line 90, which influenced the planning of the motorway's corridor. In some places the chosen corridor leads along the flood bed of the River Hernád, thus, the motorway's embankment is also to act as the primary flood protection dike in some sections (e.g. between Garadna-Hidasnémeti, Garadna-Forró, Arnót-Miskolc). The track of the planned motorway is almost parallel with the River Hernád, which means it leads along the border of Cserehát Hills and the valley side of the Hernád (Fig. 3).

The examined motorway is planned for a driving speed of 130 km/h, consequently the vertical and the horizontal technical parameters are appropriate for this speed. It is planned to lead partially along a whole new track, and to partially use the track of the existing Main Road 3, with 2+2 physically separated lanes and a 26.60 m wide crown. The crown of the crossing roads is 12.0 m

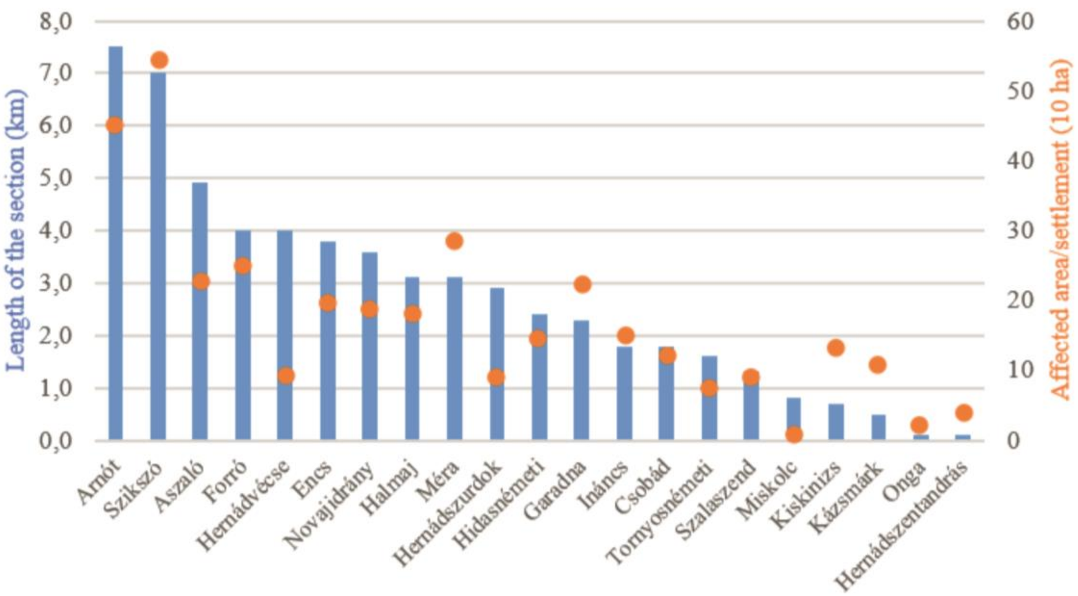


Fig. 2 Affected area of settlements and the length of the motorway section

and the parallel service roads are 7.00 m wide (the above mentioned technical parameters are summarized in the permitting plan: TURA-TERV Ltd. et al., 2016).

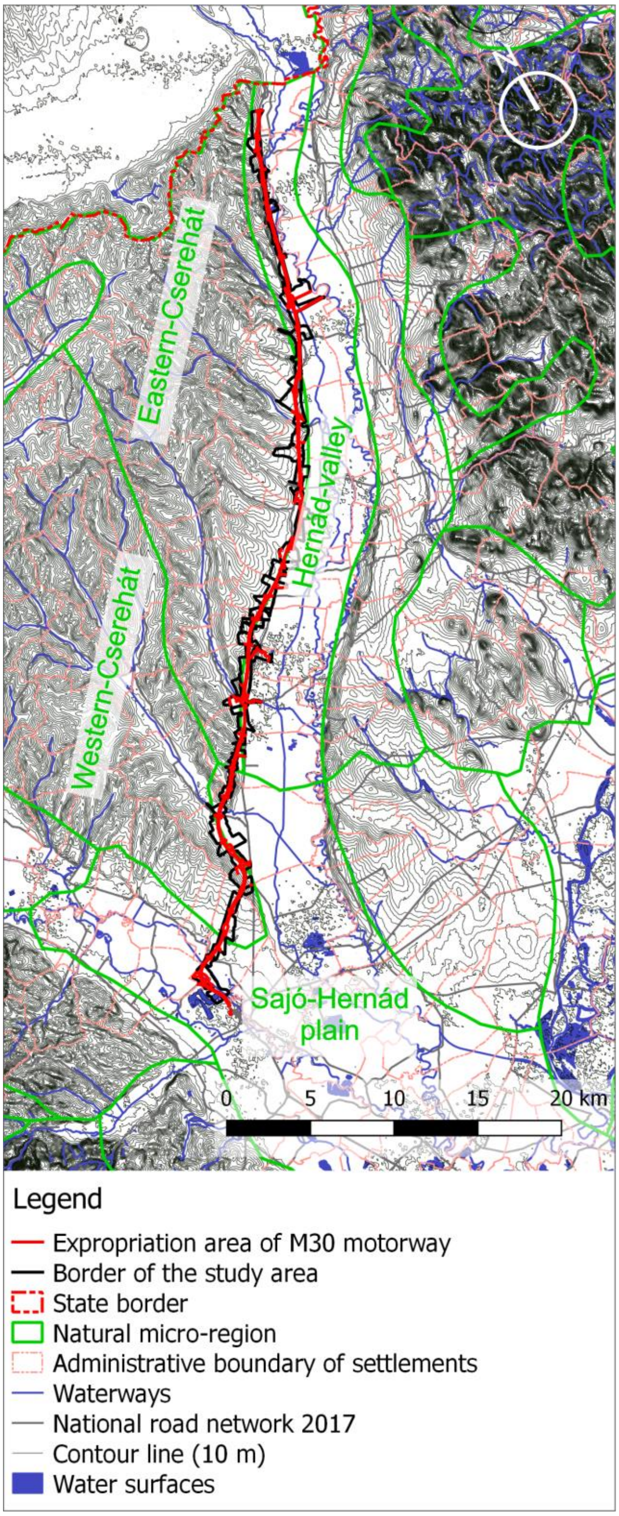


Fig. 3 Hydrological and topographical conditions of the study area

METHODS

The present analysis is a case study about the Hungarian motorway planning practice. According to Flyvbjerg (2006) single case studies can serve as a basis for drawing more general conclusions, provided that the case in question is sufficiently rich and illustrative. The M30 Motorway was considered to be a particularly interesting case due to the diversity of the existing valuable cultural and natural landscape elements in this region, the nearness of the River Hernád and the remaining traditional land uses. Land uses are considered to be traditional, if the land use in question is extensive cultivation at a small-scale existing on the particular site for at least 100-150 years.

As a primary source the findings of the landscape, green space management and environmental protection studies prepared for the modification of the affected settlements' urban plans (Department of Landscape Protection and Reclamation, 2016) were used. All the affected settlements located between Miskolc and Tornyosnémeti were included in the analysis. The studies focus on current land use, valuable cultural and natural landscape elements of the affected area (which must adjust to plot borders because of the plan type), scenery, potential conflicts between the motorway and the surrounding land uses. Proposals are also expected to be formulated for the future land uses (on the level of regulations within the frame of the urban plans). In these studies – made for the urban plan modification – other plans (environmental impact assessment, design plan) and historical maps (18-20th centuries military survey maps of Hungary) were also considered. As a secondary source (besides maps and plans) field surveys were carried out alongside the entire track of the planned motorway. The expected land use conflicts were evaluated based on the field survey and the list of non-protected landscape elements is mainly based on this too (e.g. in the case of unique landscape elements national databases were not available for these settlements). As a tertiary source, the study area was analysed by using existing databases. For the preparation of maps shown in the research, the Open Street Map database, the Hungarian Road Network 2017 (provided by the Hungarian Public Road Non-profit PLC), the protected areas (provided by the Ministry of Agriculture), the expropriation area of the planned M30 Motorway (based on the design plan) and the SRTM terrain model (interpolating 10 m contour lines) were used. For some figures the topographic map was used as a base map. The 'Las Palmas' version of Quantum GIS open source program was used.

Besides the summing up of the plans in connection with the planned motorway, some basic principles were determined based on the above-mentioned environmental impacts of the motorway implementation in connection with physical aspects related to valuable landscape elements and land uses. They are proposed to be considered in a road planning process so that the negative impacts on the landscape could be minimized. These are the followings:

(1) Ensure the continuation of traditional land uses
(2) Protection of valuable natural and cultural landscape elements (independently from the fact whether they are protected or not by law)
(3) Fitting to the current land uses so that the potential conflicts could be minimized between the motorway and the surrounding land uses

(4) Maintaining the ecological and functional connections in the landscape (minimization of fragmentation)
(5) Maintaining the valuable scenery relations and minimization of the negative visual impacts on the landscape.

RESULTS AND DISCUSSION

The directly affected land uses located within the expropriation area – based on the field survey – are mainly arable lands, but orchards, acacia forests and oak forests, small plot vineyards and vine cellars, horticultural area with old walnut trees and wet pastures are also to be found. Both the small plot vineyards and the horticultural areas are traditional land uses in the region: Aszaló and Szikszó are parts of the Vine Region of Bükk. In the case of the section between Miskolc and Aszaló the planned motorway leads across the hilly vineyards and orchards, with a completely new track in the landscape and does not fit to any existing linear landscape elements or the topographical conditions (see the motorway section between Szikszó and Aszaló on Fig.4 where those land uses are shown which are sensitive for the impacts of the planned motorway). An artificial, 100-250 m wide flood control channel of the River Kis-Sajó needs to be modified in Arnót because of the chosen road corridor.

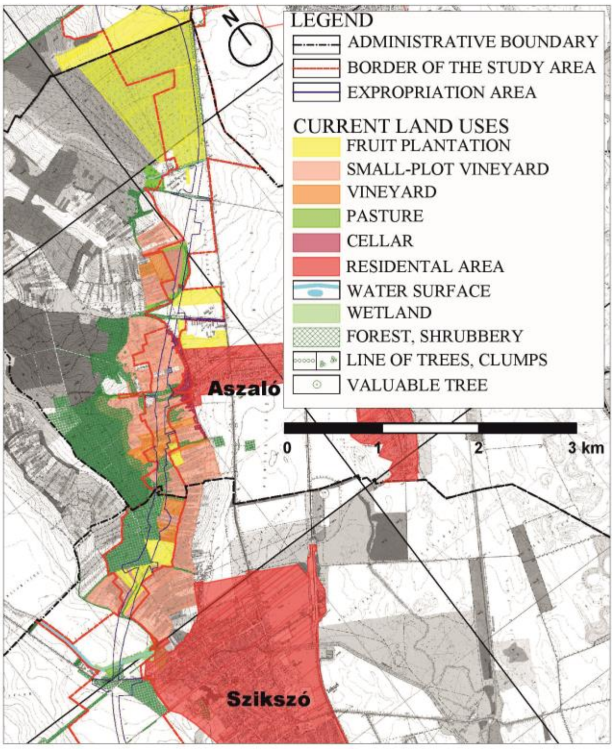


Fig. 4 The section between Szikszó and Aszaló doesn't fit to the topographical conditions and the current land use structure

There are natural values in the study area protected at international (Natura 2000 areas) or national level (ex lege – that is protected by law – protected mottes, elements of the National Ecological Network) or at local level (local Nature Conservation Area). Furthermore, numerous valuable cultural and natural landscape elements are to be found here which are not protected by law, e.g. traditional land uses, unique landscape elements (see the definition below Table 1). Based on the overview map of the national, international natural values (Fig. 5a) it can be stated that the chosen corridor is quite favourable, since it leads along the border of valuable landscape elements and land uses or it bypasses them. The affected valuable landscape elements per settlements are summarized in Table 1, which contains not only the protected areas but also the other non-protected landscape elements. Affectedness was considered as a real area demand, so these valuable elements are within the motorway's expropriation area (they are endangered or would disappear during the construction of the motorway). Over the total length of 56 km, passing through 21 settlements, the corridor affects one Nature Conservation Area protected at local level (in Szikszó, namely "Magyar-hegyi macskaherés"), two Natura 2000 areas (close to their border), 14 ecological corridors and 10 buffer areas of the National Ecological Network. The ecological corridors are mostly waterway crossings (10 out of 14). The planned motorway is also close to an ex lege protected motte (Méra) and a spring (Novajidrány), but they are outside the expropriation area. Besides the mentioned natural values, a lot of non-protected valuable landscape elements are also endangered (see details in Table 1), such as unique landscape elements, lines of trees, small plot vineyards, orchards, horticultural areas with old and characteristic walnut trees.

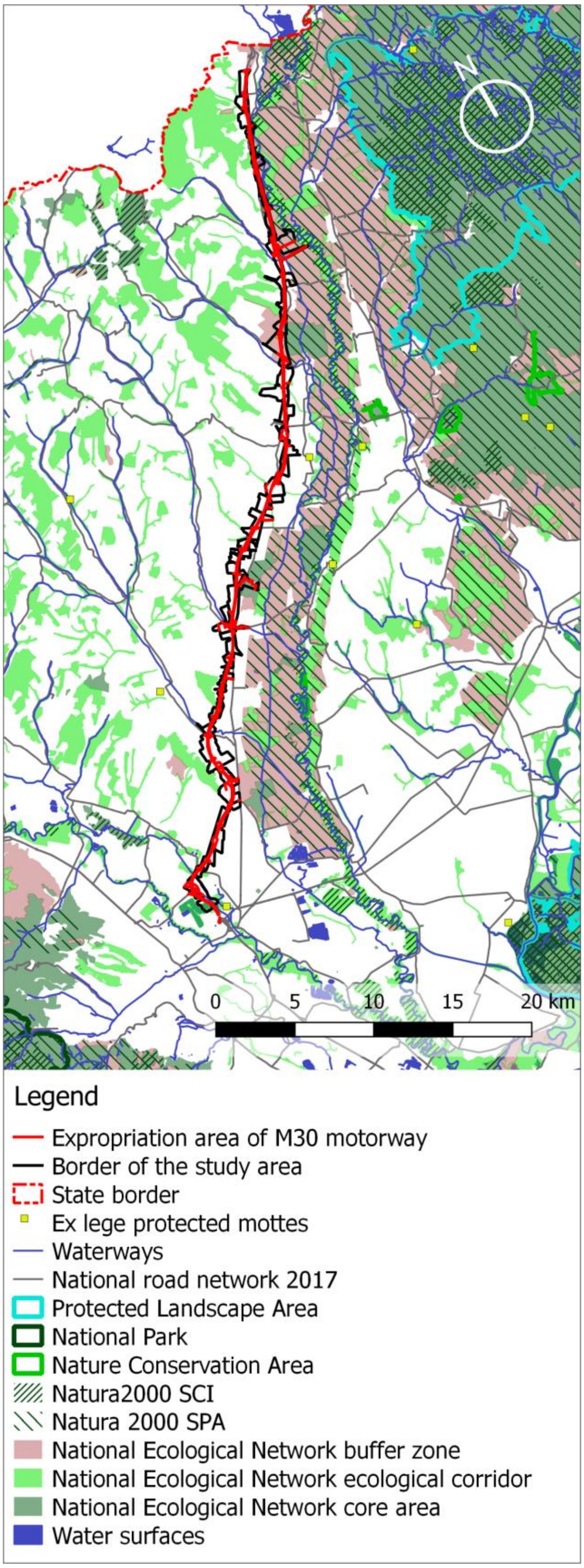
A length of 9.6 km out of the 56 km (sections between Hernádvécse-Hidasnémeti and Szikszó-Arnót) of the planned motorway (see Table 1) is within the priority area of scenery conservation (defined in Hungary's National Spatial Planning Plan), due to the remaining traditional land use (e.g. near Aszaló), the Valley of the River Hernád, and the traditional settlement structure (Hernádszurdok). The track of the motorway leads along 7-8 km away from the Zempléni Protected Landscape Area between Ináncs and Tornyosnémeti, which is a valuable scenery relation between the protected area and the motorway (providing a "beautiful view" from the motorway). According to the field surveys there are some local valuable scenery elements – e.g. line of trees, shrubberies, waterways and wetlands alongside them, gallery forests – which would disappear as a result of the construction of the road (see Fig. 6 and Table 1).

In the case of the M30 Motorway the main expected land use conflicts per settlements are summarized in Table 2. The most common conflicts which occur: potential pollution from rainwater drainage into living water (2), disturbance of residential areas and recreational facilities (3), and unfavourable changes in the local road transport because of the disappearance of an existing main road (6). In connection with the last mentioned conflict the main problem is that motorways are toll roads in Hungary, while the use of the main roads is free of charge, so probably the traffic will flow back to the settlements. In the case of Aszaló the motorway would be a significant functional barrier, because it separates the vineyards from the vine cellars, so these will be difficult to approach.

Table 1 Affected landscape values per settlements

Settlement	Natura 2000 area SPA/SCI	Nature Conservation Area protected on the local level	National Ecological Network		Unique landscape values and valuable scenery relations		Traditional land use/valuable landscape elements
			ecological corridor (pcs)	buffer area (pcs)	priority area for scenery conser-vation[1]	characteristic elements/ unique values[2]	
Miskolc	-	-	1	-	-	-	-
Arnót	-	-	2	-	affected	viewpoint	vineyard with small plots
Szikszó	-	"Magyar-hegyi macskaherés" Nature Conservation Area	2	-	affected	viewpoint, line of trees	traditionally cultivated hilly area: small plot vineyards, shrubberies
Onga	-	-	-	-	-	viewpoint	horticultural area with old walnut trees
Aszaló	-	-	-	-	affected	wine cellars, onetime farm of the landed gentry, line of trees	traditionally cultivated hilly area: small plot vineyards and vine cellars, orchards
Halmaj	-	-	-	-	-	-	horticultural area with old walnut trees, local ecological corridor
Kiskinizs	-	-	-	-	-	-	local ecological corridor
Kázsmárk	-	-	1	-	-	roadside crucifix	orchards, old poplar trees
Ináncs	-	-	1	-	-	-	-
Csobád	-	-	1	-	-	line of trees	local ecological corridor
Hernádszentandrás	-	-	1	-	-	-	not protected spring and wetland around it
Forró	-	-	2	-	-	onetime mill, roadside crucifix (3 pcs)	-
Encs	-	-	-		-	sun-dial, 1956 Memorial Tree	the gate of the settlement (with unique values)
Méra	-	-	2	3	-	line of trees (nearby an ex lege protected motte)	vineyards and orchards
Szalaszend	-	-	-	1	-	line of trees	-
Novajidrány	HUBN10007	-	1	1	affected	viewpoint, cemetery, funeral home, spring, onetime hunter mansion (nearby an ex lege protected spring)	small plot vineyards and orchards
Garadna	HUBN10007/ HUAN20004	-	2	2	-	roadside crucifix, line of trees	sports ground with old trees
Hernádvécse	HUBN10007/ HUAN20004	-	4	1	affected	-	-
Hernádszurdok	HUBN10007/ HUAN20004	-	1	1	affected	-	traditional settlement structure
Hidasnémeti	-	-	4	-	affected	roadside crucifix, line of trees	old elm tree
Tornyosnémeti	-	-	-	1	-	line of trees	-

[1] According to the National Spatial Planning Plan of Hungary.
[2] Unique landscape values are artificial or natural landscape values that have significance for the society from a natural, historical, cultural, scientific or aesthetic point of view (according to the Hungarian nature conservational act).
HUBN10007: „Zempléni-hegység a Szerencsi-dombsággal és a Hernád-völggyel" SPA area
HUAN20004: „Hernád-völgy és Sajóládi-erdő" SCI area



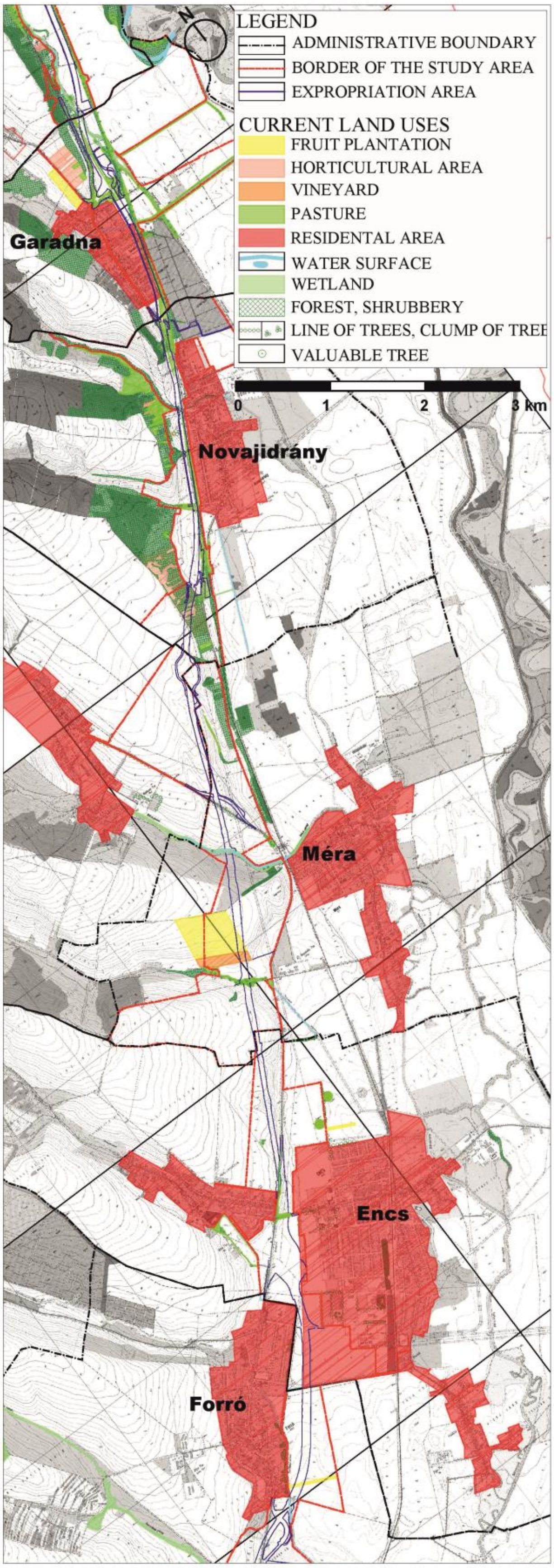


Fig. 5 a) Overview map of the national, international natural values (nature conservation by law); b) The section between Forró and Garadna doesn't fit to the settlement structure and the new motorway causes many land use conflicts

Each mentioned conflict is a long-lasting and irreversible one (if a land use termination/changing is not considered as a "resolution" of the conflict). The main conflict in the case of the section between Forró and Garadna is the closeness of residential areas (on average within 250 m, in some cases within 50 m), which is shown in Fig. 5b. The visual conflicts are considered to be significant when a minimum of 4 m high fill or 4 m deep cut is needed as an earthwork or there is a huge connecting facility (e.g. resting area, junction) and the residential areas are within 1 km off the planned motorway and there is no visual barrier (e.g. forest) (see conflict 7 in Table 2).

The possibilities of landscape protection related to motorway planning – considering both natural and cultural aspects – are basically determined by the corridor and the exact road track within the corridor. In this case – during the preparation of landscape studies made for the modification of the affected settlements' urban plans – we proposed some track modifications in the phase of the design plan, because of the endangered valuable landscape elements (e.g. in order to protect lines of trees, unique landscape elements, and fitting into historical land use structure). But only one proposed modification was accepted in the case of Novajirány, where the original track affected an ex lege protected spring's source area (with old maple trees, willows). In the other cases (see the affected valuable landscape elements in Table 1) most of the valuable elements will perish or if it is possible they will be relocated (e.g. roadside crucifixes). The affected valuable landscape elements are mostly of local significance (and not protected by law). Compensatory measures are planned for the forests (it is regulated by law in Hungary) and due to local demands (in the case of Garadna, where a sports ground would be cut across by the motorway or in the case of Novajidrány, where a funeral home would be destroyed). The mitigation measures for the possible land use conflicts can be plantations alongside the motorway or noise walls. In order to ensure the ecological connections, four ecological bypasses and five eco tunnels are planned along the 56 km long section (if the other waterway crossings are disregarded, which need to be built and also provide ecological connections: 10 of them are suitable for smaller mammals and two of them are suitable for big mammals). The number of the separate ecological bypasses is exactly the same as the number of the locations where the planned motorway cuts forests. It is important to note that the significant big mammal (boar, roe and red deer) migration corridors cover long sections according to the EIA (TURA-TERV Ltd. et al., 2016), and in the planning phase of the EIA there were seven planned ecological bypasses for big mammals originally (four separate and three combined with a waterway). So all in all there are some facilities which are planned to ensure ecological

Fig. 6 Some examples for the disappearing/endangered valuable landscape elements because of the motorway

Table 2 Probable main land use conflicts after the implementation of the motorway

Settle-ments / Land use conflicts*	Miskolc	Amót	Szikszó	Onga	Aszaló	Halmaj	Kiskinizs	Kázsmárk	Ináncs	Csobád	Hernádszentandrás	Forró	Encs	Méra	Szalaszend	Novajidrány	Garadna	Hernádvécse	Hernádszurdok	Hidasnémeti	Tornyosnémeti
1		X																			
2		X	X					X		X	X			X			X	X			
3		X										X	X			X	X		X	X	
4			X		X																
5			X																		
6											X	X	X			X	X	X	X	X	X
7	X	X	X		X							X	X	X	X	X	X		X	X	

*1: Wastewater treatment plant near the resting area (smell)
*2: Rainwater drainage into living water (potential pollution)
*3: Recreational facilities/residential area near (within 250 m) the motorway (disturbance, air pollution)
*4: Makes difficult to cultivate the vineyards, orchards (functional barrier to continue the traditional cultivating)
*5: The location of ecological bypass is not compatible with the future land use (e.g. industrial area)
*6: Makes more difficult the local road transport (the current main road No. 3. can't be used furthermore as a main road)
*7: Visual conflicts because of the motorway technical parameters (unfavourable visual element)

connections, but after the construction of the motorway migration of the wildlife will be much less possible than before.

As much as the basic principles set out based on the potential impacts on the landscapes are concerned, it is not a black and white issue. Since a motorway is a significant intervention in any landscape, it is impossible to construct a motorway without losses. The question is only the degree of the loss. In the case of the M30 Motorway, the chosen corridor was mostly acceptable in the sections where the motorway track leads along the track of the existing Main Road 3, because it is fitted to an existing linear artificial landscape element, it is basically on the border of two natural micro-regions and can also fit into the existing land use structure. Nevertheless, it is not considered to be the best choice in places where it separates vineyards from vine cellars, where it is located within 50 meters from residential areas or where it passes through small vineyards or gardens instead of the arable lands of the nearby plain.

CONCLUSIONS

Field surveys are indispensable in the Hungarian motorway planning practice in order to list all the valuable cultural and natural landscape elements, since the available databases are insufficient for this purpose (e.g. unique landscape elements, local ecological corridors). After listing the valuable landscape elements, the determination of the valuable land uses and the analysis of the probable land use conflicts, the probable negative impacts of the motorway can be minimized by technical solutions (e.g. noise wall, ecological bypass), by plantations (alongside the road and also with future forests included in urban plans), or by relocating the unique landscape elements (e.g. roadside crucifixes). In the case of the M30 Motorway compensatory measures are also planned (because of the forests and some local demands, that is a sports ground and a funeral home).

The implementation of a motorway is always a national or at least regional interest of the society, however, the directly affected settlements and their habitants' life does not necessarily become simpler in respect of land use (more difficult accessibility because of the disappearance of a lot of local transport connections), and the motorway also can also be a direct disturbance factor in the locals' everyday life too. If an existing main road track is partially used to satisfy the planned motorway's space demand, the local transport will necessarily flow back to the settlements and their main streets, which leads to growing traffic in residential areas. As for the unfavourable impacts made on the landscape, a motorway can obstruct the continuation of traditional land uses, it always changes the land use structure to a certain degree, and always is a functional and ecological barrier in the landscape. During the construction works several valuable cultural and natural landscape elements can be damaged or can perish, independently from the fact whether they are protected or not protected by law. The potential land use conflicts after the construction can arise directly between the motorway and the existing residential areas, the recreational facilities and also the cultivated lands, and finally it is also expected to lead to changes in land use in the long term.

Acknowledgements

The authors would like to thank the Hungarian Public Road Non-profit PLC and the Ministry of Agriculture for providing the basic map data for this research.

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JOURNAL OF ENVIRONMENTAL GEOGRAPHY
Journal of Environmental Geography 11 (1–2), 37–44.
DOI: 10.2478/jengeo-2018-0005
ISSN: 2060-467X

AN ASSESSMENT OF URBAN VEGETATION ABUNDANCE IN ACCRA METROPOLITAN AREA, GHANA: A GEOSPATIAL APPROACH

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Research article, received 19 February 2018, accepted 17 April 2018

Abstract

The essential role played by urban vegetation in making urban areas livable is often overlooked in many developing cities. This is the case of Ghana where its capital, Accra is developing at the expense of urban vegetation. This study was conducted at the metropolitan area of Accra to estimate how the extent of vegetation cover has changed in the period of 1986-2013, using remote sensing satellite data from Landsat TM and ETM+. Furthermore, views of key informants were assessed on changes in the livability of the city of Accra which may be attributed to loss of urban green vegetation in the city. It was found that between 1986 and 2013, 42.53 km^2 of vegetation was lost representing 64.6% of total vegetation in 1986. The rate of change in vegetation cover between 1986 and 1991 measured around 2.14% of the total land area annually. This however, reduced in the subsequent years measuring 0.26% between 2002 and 2008. Key informants interviewed, also believe that the loss of vegetation in the city creates livability concerns relating to ecosystem functioning, temperature rise and air quality. It is therefore recommended for urban planners and decision makers to address three critical concerns of resilience, sustainability and livability, which are the missing links in the city development agenda.

Keywords: remote sensing, GIS, Spectral Angle Mapper, urban vegetation, resilience, sustainability

INTRODUCTION

The role of vegetation in urban environment has become increasingly significant to planning managers and decision makers over the past few decades. This is mainly attributed to the rapid expansion of population and urban boundaries. Urban vegetation is an important pointer to urban sustainability, environmental conservation and urban planning processes of a city. Urban vegetation provides numerous benefits to urbanites living in these areas. It is therefore imperative to incorporate vegetation in the planning of urban landscapes. Whereas the developed world has a better understanding benefits of integrating urban vegetation and open space into the urban milieu for livability sake, emerging cities of Africa are rapidly expanding at the expense of urban vegetation. Williams et. al (2014) wrote on the topic "Our cities need more trees and water, not less, to stay livable". They acknowledged the new awareness on the part of government agencies of Australia for their quest for smarter city designs to curb boiling summers. Shirazi and Kazmi (2016) on the other hand wrote about the socio-environmental impacts of the loss of urban trees and vegetation in Lahore, Pakistan. They articulated the planning failure, which has led to loss of vegetation in the urban environment. They further reviewed public perception on loss of urban vegetation and open space and their implications for urbanites. This story is not different from other developing cities, including Accra, Ghana.

Ghana, like most developing countries, is undergoing rapid urbanization. Indeed, data published by the Ghana Statistical Service (GSS, 2002; 2012) indicated that the urban population increased from 23.1% in 1960 to 44% in 2000 and then to 50.9% in 2010. It was projected that the total population of Accra, the capital city will be more than doubled within the next decade (Owusu, 2013). Rapid urbanization is seen as an inevitable process which results from economic development and rapid population growth (Rimal, 2011). This places more pressure on existing urban structures including housing and transportation. Rapid urbanization, in many cases, lead to urban sprawl, which is known to convert vegetated lands to uncontrolled and unplanned residential and other urban land uses.

Ghana's development drive has focused on the exploitation of their natural environment for human betterment with less consideration for the associated negative environmental impacts, particularly on green environment and opened spaces, which in turn impacts human life negatively. The net effect is the emergence of large urban centers such as Accra with an economic landscape dominated by buying and selling on open streets and urban sprawl, which threatens the sustainability of the city. Whiles many authors have tried to articulate the impact of ongoing urbanization on urban sprawl, waste management and land use and cover change in Accra Metropolitan Area (AMA) (Owusu 2013; Adaku, 2014; Stow et al., 2011; Appiah et al., 2014; Attua and Fisher, 2010), it is still unclear as to how this has impacted on the abundance of vegetation in the city. Perhaps what will highlight the gravity of planning failure is to estimate how much vegetated areas have been converted to other uses and how much land is still under vegetation cover (vegetation abundance). This study seeks to address this gap by utilizing Geographic Information System (GIS) and remote sensing to estimate the extent of vegetation abundance by calculating land area under vegetation in 1986, which still remains vegetated in 2013 in AMA (from 1986 – 2013), and assess the implications for living in the city. The specific questions addressed in this study are:

1. How much land area of AMA was under green vegetation cover in 1986?
2. As of 2013, how much land cover remains under green vegetation cover?
3. What are the implications for vegetation cover loss?

THE NEED FOR URBAN VEGETATION

Researchers have different ways of categorizing urban vegetation. Some classify it as urban forest, parks and green spaces, gardens and lawns, wall or roof plants, and wetlands (Guntenspergen, 2010). Others identify it as roadside trees, greenbelts in streets, green areas in parks, grasslands and aquatic green spaces (Huang et al., 2012). More simply, some have divided urban vegetation into three types: relict (or remnant) i.e. natural communities retained as they were before urbanization weed communities occupying new urban habitats, and artificial green spaces (Ohsawa and Da, 2010). Another way of looking at urban vegetation is according to its three main types: natural plants, semi natural plants, and introduced plants. Natural plants are those that existed before city construction. The major component of semi natural vegetation in cities is the anthropochory community (comprising companion plants). This relies closely on anthropogenic (human) interference under urban habitats and plays a special role in composing urban vegetation, mainly grasses. Introduced plants can be categorized into roadside trees, urban forests, parks, gardens, street greenbelts, and so on. No matter which classification one chooses, urban vegetation plays an important role in supporting urban environment and the urban ecosystem functioning making it livable for the people. Some of the key roles of urban vegetation and for that matter the need for urban vegetation are discussed below:

1. *Urban Vegetation in Carbon Sequestration:* Carbon sequestration means capturing carbon dioxide (CO_2) from the atmosphere or capturing anthropogenic (human) CO_2 from large-scale stationary sources like power plants before it is released to the atmosphere. Once captured, the CO_2 gas is put into long-term storage (Pacala and Socolow, 2004). In photosynthesis, plants take in CO_2 and give off the oxygen (O_2) to the atmosphere as a waste gas. The plants retain and use the carbon to live and grow. When the plant withers or dies, part of the carbon from the plant is preserved (stored) in the soil.

2. *Urban Vegetation in Air Filtering*: Urban vegetation also increases air quality by removing and storing harmful airborne gases (Dwyer et al., 2014) and by physically trapping particles, such as dust from the atmosphere (Beckett et al., 2000). Plants help to clean the air of pollutants, such as particulate matter. The pores of leaves remove dangerous compounds, such as nitrogen oxide, sulphur dioxide, carbon monoxide, and ozone from the air. Nowak et. al., (2006) found that in the US, urban trees remove about 711,000 metric tonnes of air pollutants every year, which confers an estimated \$3.8 billion of economic value.

3. *Urban Vegetation in Reducing Heat*: Vegetation can reduce temperature or the heat island effect. The heat island effect is basically an area within the “urban environment that’s a lot warmer than the rural area surrounding it” (National Geographic 2013). The excess heat is caused by impervious surface’s ability to hold and radiate heat, as well as energy created by cars, public transit, buildings and people throughout the urban landscape. Increasing the amount of canopy cover would absorb heat from the environment, making it a much more comfortable and regulated climate to live in.

4. *Urban Vegetation in Recreational and beautification function*: Urban vegetation also provides a social value to the urban landscape. The aesthetic value of vegetation can enhance residents’ satisfaction, attachment and sense of responsibility, thereby, improving their overall well-being (Groenewegen et al., 2015). Urban greenery is often the host of many outdoor leisure activities for urbanites and can also provide opportunities for education and encourage physical activity. Access to urban green spaces is usually free to all, which is why they promote social inclusion and provide opportunities for social interaction (Swanwick et al., 2013).

5. *Urban Vegetation in Microclimate and ecosystem stability*: Ecologically, vegetation plays extremely important roles in reducing storm water runoff, acting as an absorbent for pollutants, microclimate regulation (Harlan et al., 2006; Jenerette et al., 2007) and reducing temperatures within cities. According to De Groot et. al. (2002), vegetation may also retain and store water; this allows for natural drainage which reduces surface runoff and, therefore, reduces the risk of flooding in urban areas. Another benefit of vegetation in an urban environment is that it provides habitat for wild life and, therefore, can help maintain and enhance biological and genetic diversity (Attwell, 2000). People with better access to urban parks live longer (Mitchell and Popham, 2008), exercise more (Bai et. al. 2013; Thompson 2013), have better social cohesion (Kazmierczak, 2013), and report better health generally (van Dillen et al., 2012)

STUDY AREA

This study was conducted in the AMA, Ghana. AMA is bounded by the Gulf of Guinea in the south, by the University of Ghana in the north, by Tema Township in the east and by Korle Lagoon in the west. Figure 1 shows the map of the study area.

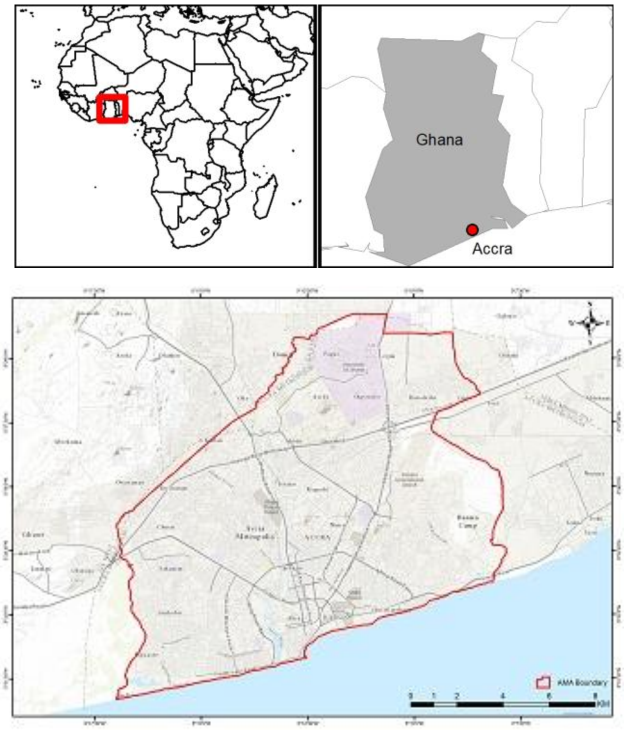

Fig. 1 Location of the study area – Accra Metropolitan Area

The total built-up area is about 25 km east to west and about 12 km north to south (Owusu and Asante, 2013). Topography is generally low-lying and undulating in some areas. The higher elevation parts are about 240 meters above sea level. The rest of the area is about 60 meters above sea level. The drainage catchment area extends from the eastern boundary of the Nyanyanu river catchment on the west of Greater Accra regional boundary to river Laloi, east of Tema Municipal Area. The AMA is the most urbanized district in the Greater Accra Region. It has an estimated population of 1,848,614 of which 887,673(48.02%) are males and 960,941(51.98%) females in 2010 (Ghana Statistical Service, 2012). It also has the highest literacy rate of 85.1%. Over 68% of the population aged 15 years or older is economically active. A lot of commercial activities are concentrated within the AMA with almost all major businesses in Ghana having their headquarters located there. The daily influx of people from dormitory towns makes the daytime population figures far higher than the domicile population estimate.

AMA lies in the coastal savannah agro-ecological zone. There are two rainy seasons. The average annual rainfall is about 730mm, which falls primarily during the two rainy seasons. The first begins in May and ends in mid-July. The second season begins in mid-August and ends in October (AMA, 2013). There is little variation in temperature throughout the year. The recorded average temperature in the coolest month (August) is 24.7oC and the hottest month (March) is 28^{o}C. Due to the area's proximity to the equator, it practically experiences a uniform temperature all year round. Relative humility is very high. It ranges from the daily minimum of 65% during mid-day to as high as 95% during the night. The local wind direction is predominantly West-South-West to North-North-East. Wind speed normally ranges between 8-16 km/hr. There are evidence suggesting that the present vegetation found around the metropolitan area have been altered and could possibly be attributed to both climate and anthropogenic factors. Much of the area is believed to have been covered by dense forest, which remnants could still be found surviving within the area (AMA 2015). There is very little variation in temperature throughout the year. The mean monthly temperature ranges from 24.7°C in August (the coolest) to 28°C in March (the hottest) with annual average of 26.8°C. As the area is close to the equator, the daylight hours are practically uniform throughout the year. Relative humidity is generally high varying from 65% in the mid-afternoon to 95% at night. The predominant wind direction in Accra is from the WSW to NNE sectors. Wind speeds normally range between 8 to 16 km/hr. High wind gusts usually occur with thunderstorm activity. There is evidence to suggest the vegetation of the metropolitan area has been altered in the more recent past century by climatic and other factors. Much of the metropolitan area was believed to have been covered by dense forest of which only a few remnant trees survive (AMA, 2015).

Climate factors, combined with the topography and human activities, particularly cultivation, have imposed new vegetation structure similar to those of the southern Sahel, Sudan and Guinea Savannas north of the Accra plains. The vegetation of the study area can be grouped into three (3) broad zones; comprising of the shrub land, grassland and the coastal lands. The shrub lands occur commonly around the Western outskirts and the northern slopes towards Aburi Hills. It has dense clusters of short trees and shrubs, with an average height of around 5 meters. The grasslands are a mixture of grass species similar to those found in the undergrowths of forests. They are very short, barely exceeds 1 meter above ground. Ground herbs are found on the edge of the shrub. They include species, which normally flourish after fire.

The coastal zone comprises two vegetation types, wetland and dunes. The coastal wetland zone is highly productive and an important habitat for marine and terrestrial-mainly bird life. Mangroves, comprising two dominant species, are found in the tidal zone of all estuaries sand lagoons. Salt tolerant grass species cover substantial low-lying areas surrounding the lagoons. These grasslands have an important primary production role in providing nutrients for prawns and juvenile fish in the lagoon systems. In recent times, wetlands are however being encroached upon (AMA, 2015). The dune lands have been formed by a combination of wave action and wind. They are most unstable but stretch back several hundred meters in places. There are several shrub and grassland species, which grow and play an important role in stabilizing dunes. Coconuts and palms grow well in this zone, providing protection and an economic crop. Most of the coconuts were planted in the 1920s but it is estimated that over 80% of those plantations have disappeared as a result of felling, disease and coastal erosion. The loss of these trees is one of the principal reasons for the severity of erosion in some areas.

METHODS

Assessment of urban vegetation abundance and change using remote sensing

There are diverse methods for assessing urban vegetation. The earliest method for urban vegetation investigation was manual statistics within a city boundary (Francis, 1987). The investigation results were usually shown by a total index or distribution indices in terms of a whole city or neighbourhood of the city, respectively. Obviously, this method is quite inefficient, imprecise, and time consuming. With the advancement in technology, urban vegetation can now be monitored, mapped and analyzed using remote sensing and GIS techniques. Some commonly used remote sensing techniques in urban vegetation analysis include Normalized Differenced Vegetation Index (NDVI), vegetation cover change detection, land cover classification (Villa et al., 2012; Rahman et al., 2011; Li et al., 2011). Satellite remote sensing is undoubtedly, one of the most effective tools for monitoring vegetation cover and change because it can guarantee the availability of extensive datasets of large spatial (up to global coverage) and temporal (back to the 1970s) coverage. Landsat TM or ETM+ data are the most popular satellite remote sensing data sources on an urban scale (Villa et al., 2012). In a study by Rahman et al. (2011), the pattern and nature of the interrelationship between urban sprawl and urban vegetation loss in Dhaka, Bangladesh was shown using NDVI analysis. Another study by Li et al. (2011) indicates vegetation change trends based on regression model by fitting simple linear regression through the time series of the integrated NDVI in the growing season for each pixel and calculating the slopes.

This study used Landsat TM and ETM+ data and applied spectral angle mapper algorithm (Table 1) to assess the urban vegetation abundance in AMA.

Table 1 Landsat Satellite Images used for the study

Satellite	Image acquisition Date	Spatial Resolution	Path/row
Landsat 5 Thematic Mapper (TM)	December 1986	30 m	196/ 053
Landsat 5 Thematic Mapper (TM)	January 1991	30 m	196/ 053
Landsat 7 Enhance Thematic Mapper (ETM+)	December 2002	30 m	196/ 053
Landsat 7 Enhance Thematic Mapper (ETM+)	February 2008	30 m	196/ 053
Landsat 7 Enhance Thematic Mapper (ETM+)	December 2013	30 m	196/ 053

Data source and preparation

The images used in this study were Landsat 5 Thematic Mapper (TM) images, and Landsat 7 Enhance Thematic Mapper (ETM+) Images. Table 1 shows details of image data acquired for the study. The images were downloaded from United States Geological Survey (USGS) web page.

The Landsat calibration converts Landsat TM, and ETM+ digital numbers to spectral radiance or exoatmospheric reflectance (reflectance above the atmosphere) using published post-launch gain and offset values (Landsat Calibration Manual) (Chander et al., 2004; Micijevic, 2016). The Landsat Standard Calibration was followed. The resultant image was imported into FLAASH for atmospheric correction. Using Envi 5.3 software (ITT Visual Information Solutions, 2009); and spatially referenced before sub-setted to AMA boundary.

Image processing and analysis

The digital image processing method used in this study is classified as a supervised classification algorithm called Spectral Angle Mapper (SAM). The SAM algorithm is based on the assumption that, a single pixel in an image selected represents a single ground cover material (pure pixel), and can be uniquely assigned to only one feature class (provide end member spectra). The SAM algorithm is calculated based on the spectral similarity between two spectra. The spectral similarity can be obtained by considering each spectrum as a vector against the total number of bands. The SAM algorithm determines the spectral similarity between two spectra by calculating (Equation 1) the angle between the two spectra, treating them as vectors in a space with dimensionality equal to the number of bands (Rowan and Mars, 2003; Kruse et al., 1993; Van der Meer et al., 1997). Smaller angles between referenced and observed end member spectrum indicate a closer match to the referenced spectrum, whilst a wider angle indicates great difference between referenced and observed spectrum. Pixels further away than the specified maximum angle threshold in radiance are not classified. This technique, when used on calibrated reflectance data, is relatively insensitive to illumination and albedo effects. Equation 1 shows the calculation that the SAM algorithm (Kruse et al., 1993):

$$a = \cos^{-1}\left(\frac{\sum_{i=1}^{nb} t_i r_i}{\sqrt{\sum_{i=1}^{nb} t_i^2}\sqrt{\sum_{i=1}^{nb} r_i^2}}\right) \quad \text{(Eq. 1)}$$

SAM is a physically-based spectral classification that uses an n-D angle to match pixels to reference spectra. End member spectra used by SAM can come from ASCII files or spectral libraries, or one can extract them directly from an image (in-scene spectra). In this study, in-scene spectrum from pure pixel was used. This means that the in-scene spectra were matched with each pixel and the SAM algorithm classified each pixel based on its similarity to the end member spectrum used. Figure 2 shows the workflow of the study methodology and technical approach.

Change Mask

The change mask was built in this study to show locations that were vegetated from the base year and remains vegetated at the end of the study period. It is important to note that some locations change from vegetated surface to build (cleared) and change back to vegetation. In such situations all those areas were considered built hence the building of a change mask for extraction of locations that have remained vegetated from beginning till the end. The change analysis was built in ArcGIS environment using raster calculator tool under the spatial analyst menu.

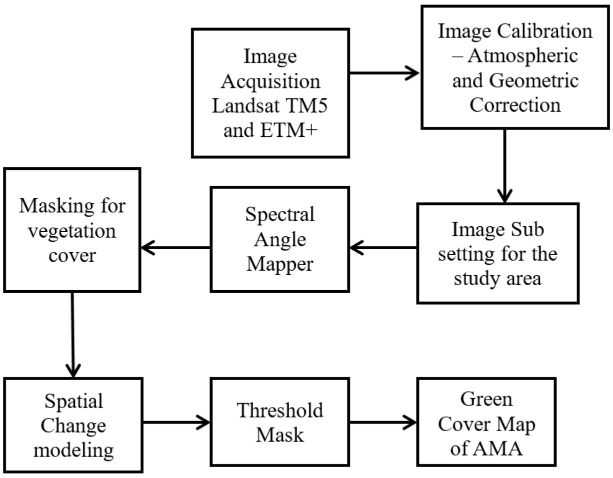

Fig. 2 Flow chart of workflow of data processing and analysis

Using the vegetation abundance image generated with SAM the change was modeled by spatial analysis. First the base year image was reclassified into vegetated and nonvegetated using Boolean classifier. Base year was 1986 (SAM1) reclassify into 1 and 0. The second year 1991 (SAM2) was also reclassified into 10 and 0 vegetated and non-vegetated, the third years (SAM3) also reclassified to 100 and 0, the fourth year (SAM3) reclassified to 1000 and 0 and the final years (SAM5) reclassified to 10000 and 0. The final change modeling was as follows:

SAM1+SAM2+SAM3+SAM4+SAM5 (Eq. 2)

The output generated were pixels with values classified as follows: 1; 0; 10; 11; 000; 100; 101; 111; 1010; 1000; 1111; 0000 etc. The position of the zero (0) indicates whether the location has changed from being vegetated at the beginning or which year it was converted from vegetation and the position of one (1) indicates when it became vegetated or has remain vegetated from the beginning (Fig. 3).

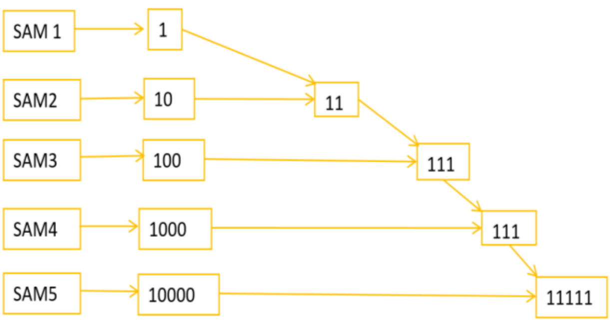

Fig. 4 The spatial modeling for identifying pixels that remained vegetated (1986-2013)

The final map for the periods were overlaid with towns and major road networks of the city which was validated with field visit to 20 selected locations. The field visit was to provide some form of accuracy assessment and we also used existing high resolution image (mainly historical) to support the validation and we found that the analysis achieved 90% accuracy.

Key informants' perception on livability of the city

The study sought the views of the general public on livability of the city of Accra, which may relate to the loss of urban vegetation. In all, 50 key informants were contacted using snowballing method for selection within five communities. The communities include East Legon, Abeka, Achimota, Cantonments and Osu. The criteria for selection include living in Accra for a minimum of 35 years, being of sound mind and willingness to express your view and also being recommended by another key informant. The selection process began with a representative of the District Assembly of the community (known as the Assemblyman or Assemblywoman), who recommends the respondent and once interview is completed, a respondent is asked to recommend the next suitable candidate. Table 2 shows the composition of respondents and their communities.

Table 2 Key informants and their respective communities of residence

Community	Male	Female	Total respondents
East Legon	8	2	10
Abeka	6	4	10
Achimota	5	5	10
Cantonments	6	4	10
Osu	7	3	10

Although the key informant interviews were male dominated, we do not think sex composition necessarily changed the outcome of the study. Structured questions relating to livability were asked in local Akan language and the responses were both recorded and written down for analysis and latter interpreted qualitatively.

RESULTS

Green areas (vegetated areas) covered about 38.01% of the total land area of AMA in 1986 (Fig. 4). This was reduced to 25.15% in 1991, representing 12.85% reduction in green areas. By 2002, the total green areas left were 17.18% and were subsequently reduced to 15.39 in 2008. It is important to note that the period 1991 and 2002 was 11 years instead of the regular 6 years used for all other period. This was due to unavailability of

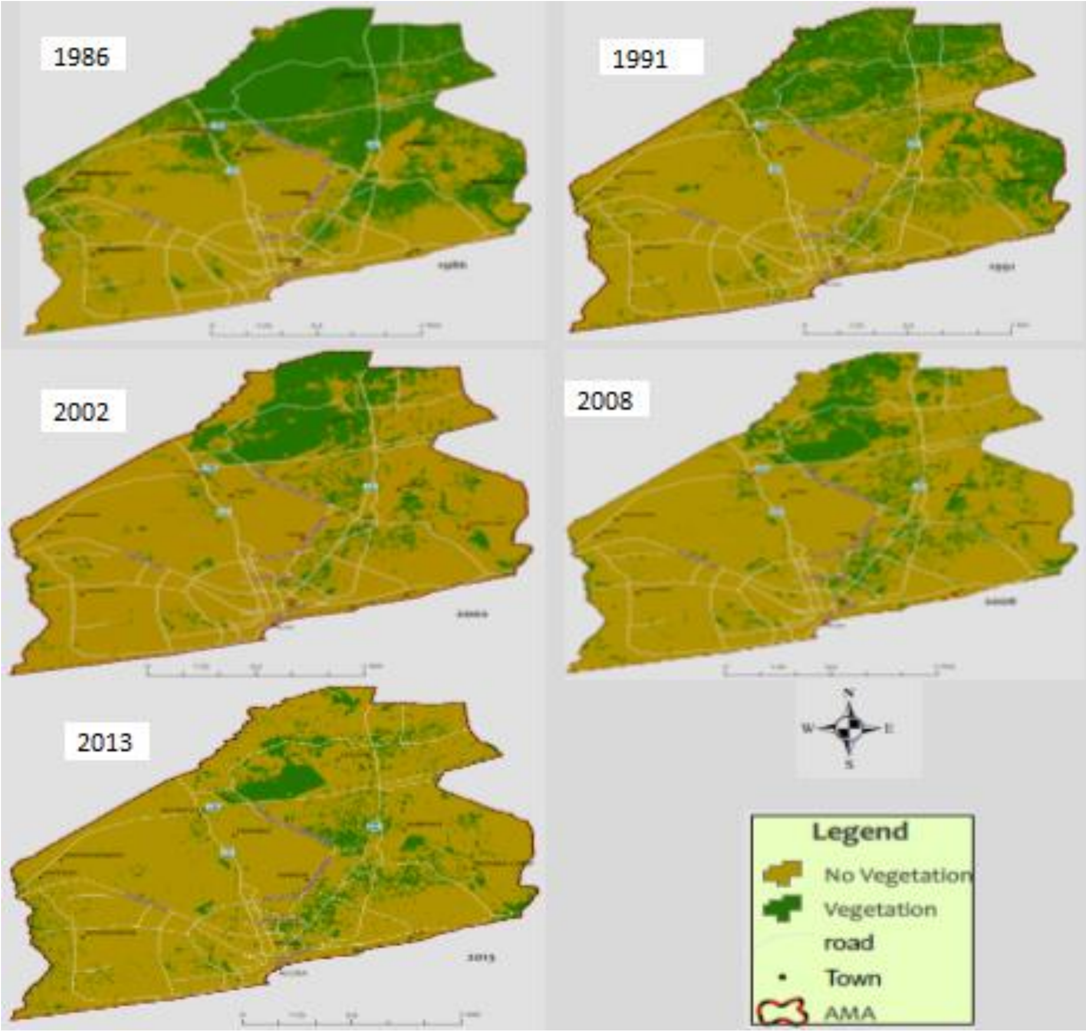

Fig. 4 Green Areas of AMA for 1986, 1991, 2002, 2008 and 2013

usable Landsat images within the required interval. As of the ending year 2013, AMA had only 13.45% of its total land area of 173km^2 left covered with greens. Figure 4, contains five images of 1986, 1991, 2002, 2008 and 2013. The images show land area covered by vegetation within and by the end of the study period. The study used change modeling to estimate areas considered as never changed. This is because there were areas that started as vegetation cover and changed to bare surface and later become vegetation again.

Figure 5 shows green cover statistics that represents never changed from green areas. It is important to differentiate between green cover areas and never changed areas since there are places or locations that changed several times. In 1986, 20.25% of the area was considered green areas or vegetated areas. This decreased to 13.36% in 1991 (within 6 years) and then further decreased to 6.37% by 2002, i.e. a period of 11 years. The vegetated areas further reduced to 6.20% 2008, although it seems like a very small margin over a period of 6 years. By the end of the study period of 2013, only 4.84% of the total land area remained vegetated, which are the areas that have never changed from being vegetated since 1986.

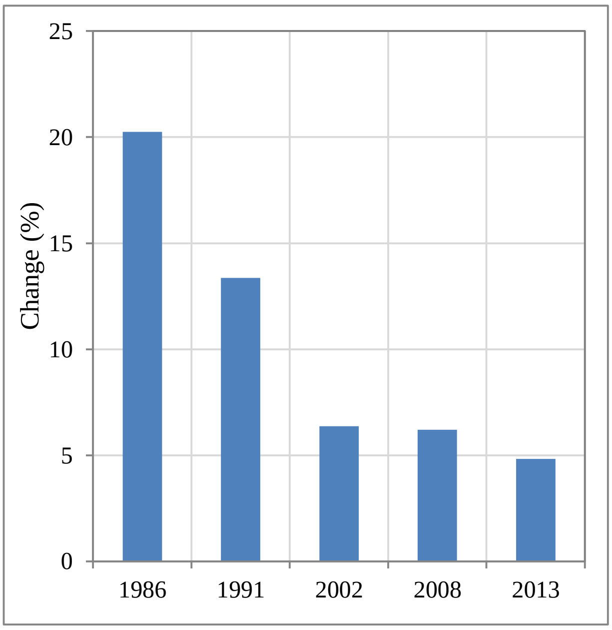

Fig. 5 Green Cover Statistics of AMA between 1986 and 2013: Extent of green cover (%) compared to the whole study area

The rate at which green cover reduced in AMA between 1986 and 1991 was shown in Figure 6. It decreased by about 2.1% per annum and reached the peak around the year 2000. By the year 2001, the vegetation of the area had reached the lowest of the times such that roughly about 6.37% of the land was left under vegetation.

Between 2002 and 2008 the rate of vegetation reduction was close to negligible. It was as low as 0.2% which suggests that there were very little open green lands to be converted to other urban land uses. The rate of vegetation reduction in 2008 and 2013 shows that there was as low conversion as 0.03 which implies no conversion of any more lands. On the ground, what was observed was infillings, which are minor conversions within existing residential and commercial areas mostly by investment capitals and external forces. Moreover, more vertical growth was observed as more high-rise buildings began emerging in the city center and emerging business enclaves.

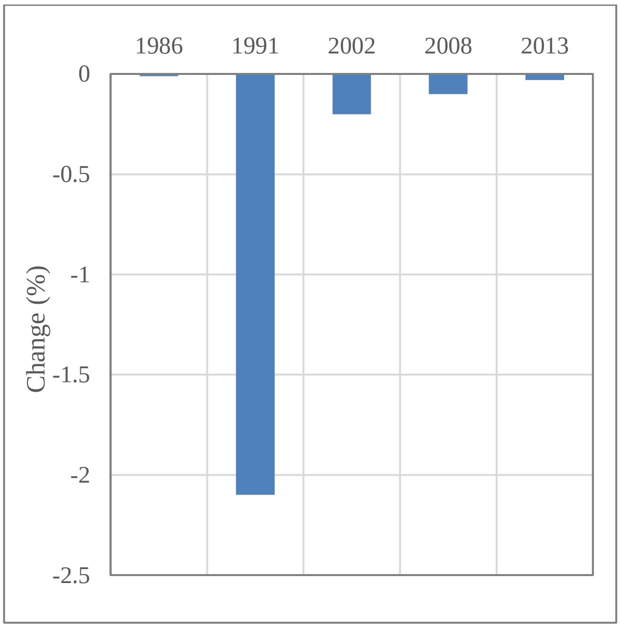

Fig. 6 Rate of green cover change (%) between 1986 and 2013

DISCUSSION AND CONCLUSION

This study was conducted with the aim of assessing vegetation abundance and change from 1986 to 2013. The data analysis shows that AMA has lost almost all the vegetation cover, leaving just about 4%. Greater part of the vegetation loss occurred between 1986 and 2002. Interestingly this period coincides with the period when Ghana embarked on Economic Recovery Program (ERP) and its associated trade liberalization which many people believe was the catalyst for Ghana's urbanization and vegetation loss. This period was characterized by conversion of green spaces, including farmland into urban uses – residential and commercial.

Localities of green cover in AMA as of 2013 include the Achimota forest reserve area (a large patch of green in the northern part of the image in Figure 4, 2013) and areas along water bodies in the metropolis. The study also shows that, areas such as Cantonments, Ridge and Legon still have some vegetation although it has reduced dramatically from the base year of 1986.

This large scale conversion of urban green spaces into other urban land uses, including paved surfaces have significant implications for the livability of Accra, which could be best explained by its residents. The study therefore dwells strongly on the opinions expressed by the key informants on the livability of the city. The key livability concerns they expressed include the rising heat, the frequency and severity of floods and air pollution. Others include concerns about the observed reduction in the rainy days, though they said they have observed increase in the intensity of rains. Even though these are views expressed by some 50 residents during field data collection, it is difficult to relegate local observations to the background. This is because they live with the problem. Also the livability concerns they expressed concur with views expressed in other studies from countries that have experienced similar conversion of urban vegetation (Gairola and Noresah, 2010; Shirazi and Kazmi, 2016). Shirazi and Kazmi (2016) wrote about the socio-environmental impacts of the loss of urban trees and vegetation in Lahore, Pakistan. Their study reviewed public perception and the story is similar to key informant's views from Accra, Ghana.

This study recommends that for AMA to address problems relating to loss of vegetation and city's livability, there is the need to take a second look at the development plans implemented. There is the need for a shift in the city's development paradigm to address what David Maddox calls the city we want, which in his view must address three major challenges, including city's resilience, sustainability and livability (Maddox, 2013). Whereas these three themes of city resilience, sustainability and livability have been in the past development agenda of the AMA, they have been pursued individually. The past three decades saw sustainable development as the order of the decade. This shifted to building resilient cities and we are now talking of livable cities. There is the need for better understanding that sustainability can be achieved without resilience and livability, even though they may seem implicit. Being a resilient city does not necessarily guarantee sustainability and livability. It is therefore important for the city of Accra to think smart and look at the city's development from these three perspectives – resilience, sustainability and livability. These will include building with the environment and living with the environment, including greens and open space management. However, AMA's biggest challenge, in achieving these recommendations including the fact that it is a resource-poor city with limited human and financial resources; lack of control over land and its development and above all favoritism and nepotism, and these have prevented effective enforcement of city bylaws and development plans to the latter.

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JOURNAL OF ENVIRONMENTAL GEOGRAPHY
Journal of Environmental Geography 11 (1–2), 45–51.
DOI: 10.2478/jengeo-2018-0006
ISSN: 2060-467X

LAND COVER CHANGE INVESTIGATION IN THE SOUTHERN SYRIAN COASTAL BASINS DURING THE PAST 30-YEARS USING LANDSAT REMOTE SENSING DATA

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Research article, received 26 February 2018, accepted 5 May 2018

Abstract

Land cover change and deforestation are important global ecosystem hazards. As for Syria, the current conflict and the subsequent absence of the forest preservation are main reasons for land cover change. This study aims to investigate the temporal and spatial aspects and trends of the land cover alterations in the southern Syrian coastal basins. In this study, land cover maps were made from surface reflectance images of Landsat-5(TM), Landsat-7(ETM$^+$) and Landsat-8(OLI) during May (period of maximum vegetation cover) in 1987, 2002 and 2017. The images were classified into four different thematic classes using the maximum likelihood supervised classification method. The classification results were validated using 160 validation points in 2017, where overall accuracy was 83.75%. Spatial analysis was applied to investigate the land cover change during the period of 30 years for each basin and the whole study area. The results show 262.40 km^2 reduction of forest and natural vegetation area during (1987-2017) period, and 72.5% of this reduction occurred during (2002-2017) period due to over-cutting of forest trees as a source of heating by local people, especially during the conflict period. This reduction was particularly high in the Alabrash and Hseen basins with 76.13 and 79.49 km^2 respectively, and was accompanied by major increase of agriculture lands area which is attributed to dam construction in these basins which allowed people to cultivate rural lands for subsistence or to enhance their economic situation. The results of this study must draw the relevant authorities' attention to preserve the remaining forest area.

Keywords: basins, land cover, remote sensing, supervised classification, Syria

INTRODUCTION

The rate of global urbanization is exponentially increasing, causing damage and reducing areas of natural vegetation (Hussein et al., 2017; López et al., 2001). Monitoring changes in land cover and understanding its spatial properties will lead to an accurate and deep understanding of how human activity affects the general ecological state of the environment (Stow and Chen, 2002; Yeh and Li, 1999). Nevertheless, the deterioration of rural area resources happens quickly, particularly in developing countries (Sarma and Saikia, 2012). In the Mediterranean area, a significant decrease in precipitation amount during the 21st century has been predicted (Lelieveld et al., 2012; Rohde et al., 2013). The decrease in total annual rainfall is expected to reach 20% by the year 2050 (Evans, 2009; Gonçalves et al., 2014). As for Syria, the current conflict and the subsequent absence of the preservation of forests and natural vegetation by the relevant authorities has played an important negative role in land cover changes (LCC). Unfortunately, there is little data available regarding the temporal and spatial aspects of land cover change in the coastal basins, however they would be important because monitoring can helps guiding sustainable development processes especially in rural areas (Marh, 1998). Sustainable development processes through appropriate basins management must take into consideration the complex interactions between human and biophysical processes which can have harmful far-reaching effects on the environment, as well as on economic activities (Panigrahi and Goyal, 2017). Hence, contemporary basins management as part of regional planning processes should include the security of the landscape and respect for the values of biodiversity (Goettle, 2002).

Remote sensing data has become an effective data source in land cover change monitoring studies. In the course of data processing, several pre-calibrated and evaluated products are generated and can be obtained free of charge (Gulácsi and Kovács, 2015). Remote sensing data and ArcGIS tools are extensively used to map and analyse land cover changes in river basins. The maximum likelihood classifier (MLC) algorithm of the supervised classification method is applicable to generate land cover maps. Basically, this supervised classification algorithm uses training sites of different land cover types for land cover mapping. In general, selecting training sites usually requires considerable time and effort and depends on the experience of the analyst and on the quality of the imagery (Aronoff, 2005). Moreover, supervised classification requires a priori knowledge about the land cover types in the study area to achieve appropriate training sites and an accurate signature file in order to derive the required land cover maps.

This empirical study attempts to identify the spatiotemporal pattern of land cover change for southern coastal river basins in Syria as study area using geospatial data. The main objective is to explore the land cover changes using multi-temporal remote sensing data with the help of geographic information system (GIS).

Specifically, the objectives are: (a) to accurately map the extent of the different land cover types in the whole study area in 1987, 2002 and 2017; (b) to detect and evaluate the land cover changes during the last 30 years; (c) to accurately map the extent of the different land cover types for the four coastal basins in the study area in 1987, 2002 and 2017; (d) to detect and evaluate the land cover changes for each basin in the study period; and (e) to conclude on the main processes and the background reasons of each land cover change pattern. The resulted maps, patterns and trends are useful information for the scientific community and decision makers to support spatial planning and sustainable development in this region.

STUDY AREA

The study area is a part of Tartous governorate in the Southern part of Syrian coastal region. It lies between latitudes 34.6438°, 35.0517° and longitudes 35.8494°, 36.3225° covering a total area of 1022 km^2. It has four river basins, of which two major river basins are the Alabrash river basin and the Hseen river basin, and two secondary river basins which are the Ghamqa river basin and the Mntar river basin (Fig. 1).

The strong influence of the Mediterranean climate brings high annual precipitation of more than 800 mm. The precipitation period is from October to May, and the dry and hot summer period lasts from June to September (Abou Zakhem and Hafez, 2010). Elevation data from the Shuttle Radar Topographic Mission (SRTM) with a spatial resolution of 1 arc-second (approximately 30m at the equator), which can be downloaded free of charge through the United States geological survey official website (USGS, 2017), were used to derive the digital elevation model (DEM) and slope maps of the study area. SRTM DEMs data are in geographic decimal degrees (Latitude and Longitude) projection, with WGS84 horizontal datum and EGM96 vertical datum. SRTM DEMs are expected to have a linear vertical absolute height error of less than 16 m, a circular absolute geolocation error of less than 20 m, and a circular relative geolocation error of less than 15 m (Farr et al., 2007). The highest elevation in the study area reaches 1093 m above the sea level in the northeast, and the maximum slope value of the study area reaches 56.4° (Fig. 2).

Depending on the values of both the elevation and the slope in the study area, the study area can be divided into three main parts: the mountains, the plateaus and the coastal areas. The mountain area is located in the northeast and east of the study area

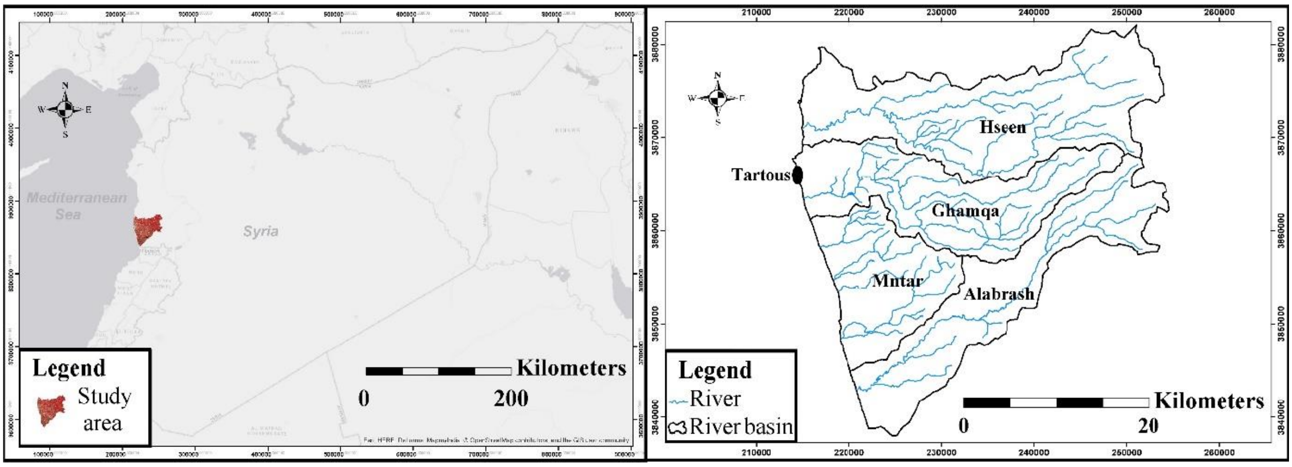

Fig. 1 The location of the study area and its four river basins

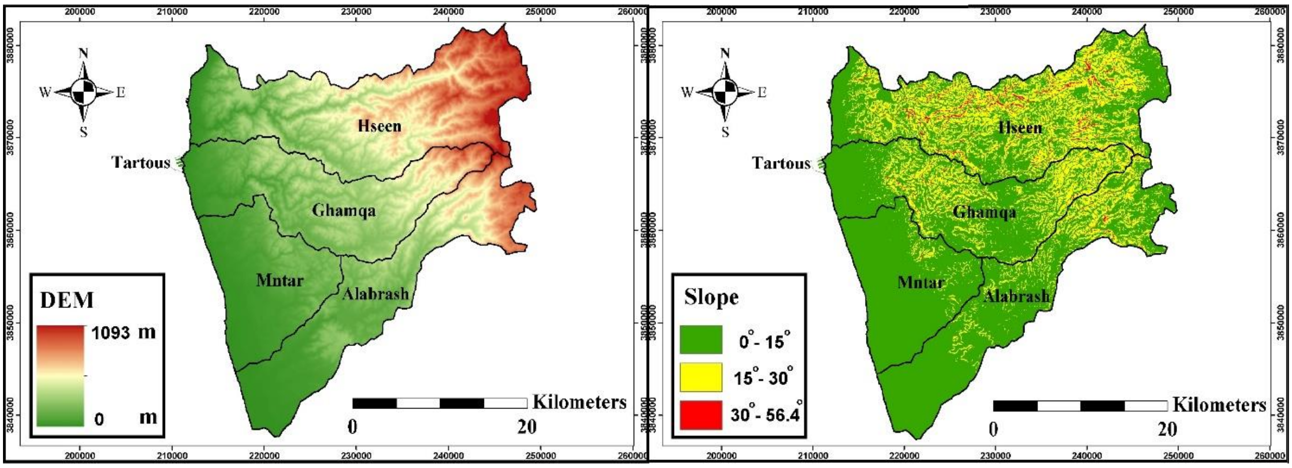

Fig. 2 DEM and slope map of the study area

between 600 m and 1093 m above the sea level, and has slopes reaching to maximum 56.4°. The mountains have good natural water resources due to the existence of many springs. In addition to widespread coniferous forests, this part has also small separate settlements with simple rural agricultural lifestyle depending on planting fruit trees and vegetables. The plateaus area is located between 200 m and 600 m above sea level, where the slope decreases and rivers become wider and broad leaved trees and olive trees are abundant, and it forms the wide home for the people in the rural areas of the Syrian coastal mountains. In this part, construction works of the biggest dam in this area, the Alabrash dam, were started in 1997 and completed in 2000. The irrigation network from this dam helps to irrigate about 10160 hectares of downstream agricultural land (Samoudi, 2015). The coastal area is located between 0 m and 200 m above the sea level and has slopes less than 15°. Tartous port is the main commercial port in this part and all of the study area. This port is located in the north of the study area in Tartous city which is the main and largest city in the study area. The Akkar plain, a fertile plain with different field crops and greenhouses, can be found in this part too.

METHODS

To analyze 30-year of land cover change, Landsat surface reflectance (SR) images were ordered free of charge through the USGS official website (USGS 2017) for getting systematic, radiometric, and geometric corrected higher-level products of the study area from Landsat-5 TM (Thematic Mapper), Landsat-7 ETM$^+$ (Enhanced Thematic Mapper Plus) and Landsat-8 OLI (Operational Land Imager) instruments data with a spatial resolution of 28.5, 30 and 30 m respectively for each VNIR multispectral band (Table 1). For the long-term assessment process, all Landsat images were selected during May to ensure maximum vegetation cover during this reference period.

The Landsat images were preprocessed individually using ArcGIS 10.2 software. They were resampled to the same 30-meter resolution, and a subset of the study area from each image was created and re-projected to the same UTM 36N zone. After that, 150 well distributed training sites representing all the main land cover classes were selected in each processed Landsat image for the supervised classification method which was applied in this study using the common maximum likelihood classifier (MLC) algorithm. This algorithm examines the probability function of a pixel for each of the classes and assigns the pixel to the class with the highest probability (Lillesand and Kiefer, 1994). Four main land cover classes (built-up area, forest and natural vegetation, agriculture lands, and water body) were identified and used to classify the images. Furthermore, the overall accuracy of the results of the whole study area and the user accuracy of each class were calculated using an error matrix of the validation data set (Congalton, 1991). After that, spatial statistics were calculated for each land cover class and thematic maps for land cover and land cover changes were generated. Finally, land cover changes in the whole study area and in each basin during the period of 30 years (1987-2017) were evaluated.

Table 1 The three Landsat images used in this study

Image acquisition date	Sensor (imagery ID)	Resolution
26 May 1987	Landsat5 TM (p174r36_5t19870526)	28.5 m
11 May 2002	Landsat7 ETM+ (LE71740362002131SGS00)	30 m
28 May 2017	Landsat8 OLI/TIRS (LC81740362017148LGN00)	30 m

RESULTS

The resulted land cover maps for the three years 1987, 2002 and 2017 are demonstrated based on the Landsat 5-TM, 7-ETM$^+$ and 8-OLI on Figure 3. The land cover maps show that there is no water body class pattern in 1987 land cover map since there was no dam yet in the study area at that year. However, the 1987 land cover map shows that there is a high ratio of the forest and natural vegetation class, in contrast to 2017 land cover map where the higher ratio of agricultural areas and the decrease of forest and natural vegetation areas. All the land cover maps show that most urban areas are located along the sea shore and increase obviously around Tartous city and the big towns.

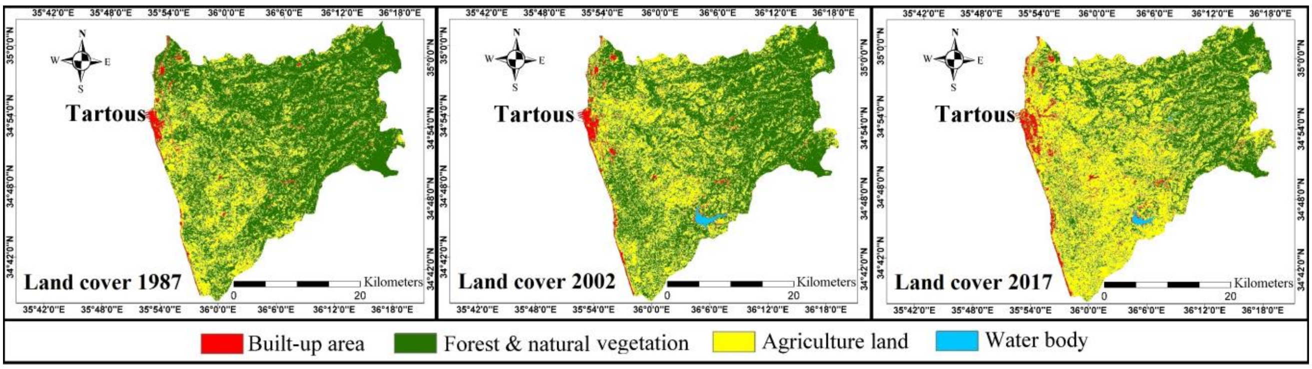

Fig. 3 Land cover maps for 1987, 2002 and 2017 from Landsat 5-TM, 7-ETM$^+$ and 8-OLI images respectively

Since there was no ancillary data available for 1987 and 2002, visual interpretation on the satellite images was applied to select the training data based on detailed local knowledge of the study area. On the other hand, a total of 160 sampling points were randomly created and used as independent data set for the validation process of the land cover map of 2017 (Fig. 4).

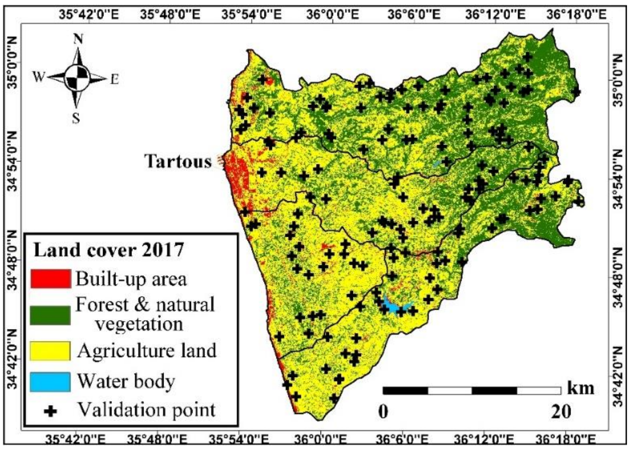

Fig. 4 Distribution of validation points on the land cover map of 2017

In order to check the validation points, a field work was executed in 2017. The observed and computed classes at the validation points in the land cover map of 2017 were used to create an accuracy matrix providing the user accuracy for each class and the overall accuracy. User accuracy was calculated by dividing the number of correctly classified pixels in one class by the total number of validation sets in that class (Congalton, 1991). The user accuracies of the built-up area and the agriculture lands classes were around 75%, while the user accuracy of the forest and natural vegetation class was 96.80% and for the water body class it was 100%. After that, the overall accuracy was calculated from the average total of all user accuracies. The overall accuracy of land cover map 2017 was 83.75% (Table 2).

Spatial analysis for all land cover maps of 1987, 2002 and 2017 was applied to calculate the different areas of each land cover class in order to investigate alterations in land cover. The area of each land cover class was calculated in square kilometers (Table 3), and as the percentage of the total study area (Fig. 5). The results were compared to evaluate land cover changes during the 1987-2002 and 2002-2017 periods.

The supervised classification result of the 1987 image shows that the largest area is the forest and natural vegetation class containing 651.84 km^2, which is 63.75% of the total study area, then it is followed by the agriculture lands class with 346.8 km^2 and 33.92% of the total study area. The remaining land cover is the built-up area class with 23.91 km^2 and 2.34% of the total study area. Also, based on the 2002 supervised classification result, the largest area is the forest and natural vegetation class with 579.79 km^2 and 56.70% of the total study area. The agriculture lands cover 407.65 km^2 and 39.87% of the total study area, and the built-up area class covers 30.06 km^2 and 2.94% of the total study area. The remaining land cover is water body with 5.06 km^2 and 0.49% of the total study area. In contrast, the 2017 supervised classification result shows that the largest area is the agriculture lands class with 582.70 km^2 and 56.98% of the total study area, followed by the forest and natural vegetation class with 389.44 km^2 and 38.08% of the total study area, and the built-up area class with 46.69 km^2 and 4.57% of the total study area. The remaining land cover is water body with 3.73 km^2 and 0.36% of the total study area.

Table 3 Land cover classes area in 1987, 2002 and 2017 in km^2

Land cover classes	**1987**	**2002**	**2017**
	Area (km^2)	Area (km^2)	Area (km^2)
Built-up area	23.91	30.06	46.69
Forest & natural vegetation	651.84	579.79	389.44
Agriculture lands	346.80	407.65	582.70
Water body	0	5.06	3.73

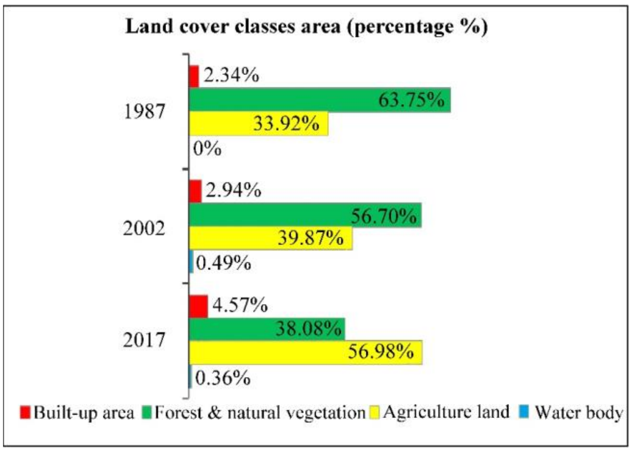

Fig. 5 Land cover classes area in 1987, 2002 and 2017 in percentage of the total study area

Table 2 Classification accuracies for land cover map 2017

Class Name	**class**	**1**	**2**	**3**	**4**	**User Accuracy**	**Validation points**
Built-up area	**1**	3	0	1	0	75%	4
Forest & natural vegetation	**2**	0	60	2	0	96.80%	62
Agriculture lands	**3**	0	23	70	0	75.30%	93
Water body	**4**	0	0	0	1	100%	1
Overall Accuracy						**83.75%**	**160 Total**

Table 4 The land cover change of the whole study area between 1987 and 2017

Land cover classes	Land cover change 1987-2002		Land cover change 2002-2017		Land cover change 1987-2017	
	km^2	%	km^2	%	km^2	%
Built-up area	6.14	0.60	16.63	1.62	22.77	2.22
Forest & natural vegetation	-72.05	-7.04	-190.35	-18.61	-262.40	-25.66
Agriculture lands	60.84	5.95	175.05	17.11	235.90	23.06
Water body	5.05	0.49	-1.329	-0.13	3.73	0.36

DISCUSSION

The study area as a whole is subject to a general decrease of natural vegetation. The largest change in land cover type was the reduction of the forest and natural vegetation class with an amount of loss reaching 262.40 km^2 out of 651.84 km^2 which is equal to almost 40% of the area of this class, and 25.66% of the total study area. Almost 72.5% of this reduction occurred during the 2002-2017 period, and just 27.5% of it occurred during the 1987-2002 period. This reduction is most likely caused by over-cutting of forest trees over time and especially during the recent conflict period and the subsequent absence of the preservation of the forest and natural vegetation. At the same time, the agriculture lands class area increased 235.90 km^2 which can be attributed to the attempts of local people to cultivate more land in rural areas for subsistence or to enhance their economic situation. Meanwhile, the area of the built-up area class has increased with 22.77 km^2 till 2017 which is almost double that of the 1987 area. However, it must be mentioned that the Alabrash dam has entered in service in 2000. So, the water body areas here represent the reservoir area in which the storage of the water is related to the annual amount of the rainfall and the irrigation operations from the dam.

The forest and natural vegetation class showed the largest land cover change, it is representative of natural vegetation in the study area. Therefore, spatial analysis was applied on the land cover changes of this class in order to evaluate the detailed trends of the changes in this class during the two main periods of the study 1987-2002 and 2002-2017 (Fig.6).

The results show that the forest and natural vegetation class lost 29.03% of its area between 1987 and 2002, while this loss reached 42.66% between 2002 and 2017 (Table 5). This increasing value reflects not only the climate change during the second period but also the negative role of the current conflict in Syria and the subsequent absence of the preservation of the forests and natural vegetation.

Land cover change analyses were executed for each basin in the study area and the results show that the Alabrash basin has the maximum forest and natural vegetation area decline in percentage relative to the basin area with 30.98%. At the same time, the Hseen basin has the maximum forest and natural vegetation area decline in square kilometres with 79.49 km^2 reduction. Meanwhile, the Mntar basin has the minimum forest and natural vegetation area decline in both square kilometres and percentage relative to the basin area with 36.92 km^2 and 21.70% respectively. Moreover, the major increase of agriculture land area could be seen also in the both Alabrash and Hseen basins with 67.65 km^2 and 77.52 km^2 respectively (Table 6). This can be attributed to the dam construction processes in these two basins in the late nineties which allowed many local people to cultivate more rural lands to enhance their economic situation or even for subsistence during the current conflict period. This increase of the agricultural land area here at the expense of the forest and natural vegetation area can be considered as a negative change in the ecosystem of the area as it most likely indicates the possibility of the built area growth in a later stage.

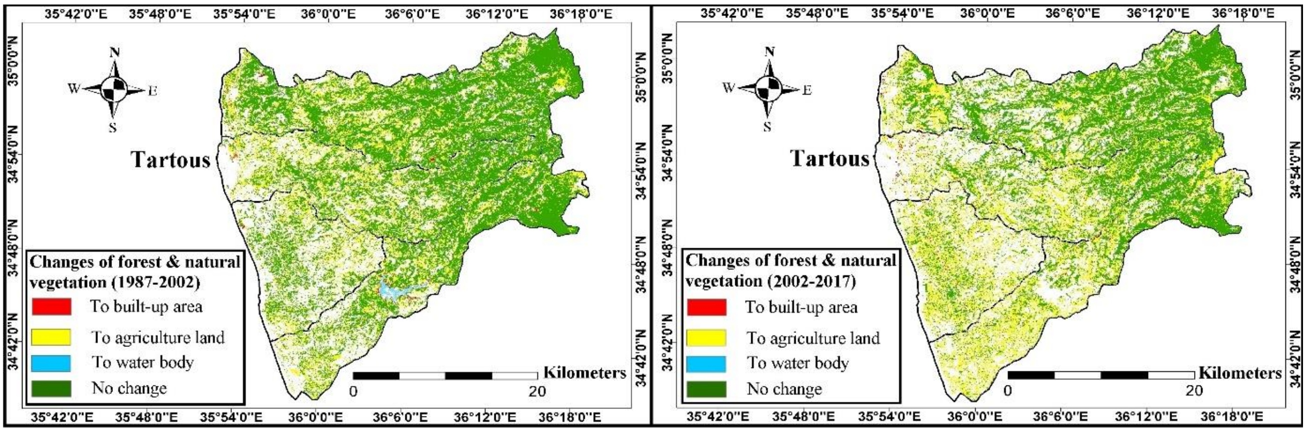

Fig. 6 Changes of forest & natural vegetation class during the 1987-2002 and 2002-2017 periods

Table 5 Patterns of forest & natural vegetation change during the 1987-2002 and 2002-2017 periods

Patterns of forest & natural vegetation change	Area in (%) of total forest & natural vegetation class area (1987-2002)	Area in (%) of total forest & natural vegetation class area (2002-2017)
Forest & natural vegetation to built-up area	0.73	1.10
Forest & natural vegetation to agriculture lands	28.65	41.53
Forest & natural vegetation to water body	0.52	0.02
No change	70.07	57.34

Also, the result of land cover change analyses for each basin in the study area shows that the Hseen basin has the smallest built-up area increase in both square kilometres and percentage relative to the basin area with 1.53 km^2 and 0.42% respectively. While, the Mntar basin has the largest built-up area increase in percentage relative to the basin area with a 4.29% increase within the basin. At the same time, the Ghamqa basin has the maximum built-up area increase in square kilometres with 8.62 km^2 increase within the basin. This increase of the built-up area in these basins is related to the growth of Tartous city in addition to the big towns and villages in the study area especially during the last few years after the arrival of large numbers of displaced families who were forced to flee their homes from the interior regions of Syria due to the current conflict. So, the attempt of some local people and real estate traders to make benefits from accommodate these families plays a main role in the growth of the construction works in these areas.

Table 6 The land cover changes of each basin during the period of study (1987-2017)

Land cover classes	1987		2017		LCC 1987-2017	
	Area km^2	Area %	Area km^2	Area %	Change km^2	Change %
Alabrash Basin (245.77 km^2)						
Built-up area	2.98	1.21	8.29	3.37	5.31	2.16
Forest & natural vegetation	159.93	65.07	83.79	34.09	-76.13	-30.98
Agriculture lands	82.85	33.71	150.50	61.22	67.65	27.51
Water body	0	0	3.20	1.30	3.20	1.30
Hseen Basin (357.82 km^2)						
Built-up area	6.98	1.95	8.51	2.38	1.53	0.42
Forest & natural vegetation	270.85	75.69	191.36	53.48	-79.49	-22.20
Agriculture lands	79.98	22.35	157.50	44.02	77.52	21.67
Water body	0	0	0.38	0.10	0.38	0.10
Ghamqa Basin (248.98 km^2)						
Built-up area	10.29	4.13	18.92	7.60	8.62	3.46
Forest & natural vegetation	149.00	59.84	79.12	31.78	-69.88	-28.05
Agriculture lands	89.68	36.01	150.86	60.60	61.18	24.58
Water body	0	0	0	0	0	0
Mntar Basin (170.03 km^2)						
Built-up area	3.65	2.15	10.95	6.44	7.29	4.29
Forest & natural vegetation	72.07	42.38	35.15	20.68	-36.92	-21.70
Agriculture lands	94.30	55.46	123.83	72.86	29.52	17.40
Water body	0	0	0	0	0	0

CONCLUSION

This study analyzed the changes in land cover of the southern Syrian coastal basins during the last 30 years, based on multi-temporal Landsat surface reflectance images from three different dates in 1987, 2002 and 2017. Supervised classification method was applied using the common maximum likelihood classifier (MLC) algorithm to classify each Landsat image into four land cover classes. Spatial analysis on each land cover map of 1987, 2002 and 2017 was applied to calculate the different areas of each land cover class in order to investigate their changes during the study period. The results show that the study area is strongly affected by a general decrease of forest and natural vegetation, especially during the 2002-2017 period, which not only reflects the climate change, but also the negative role of the current conflict in Syria. The main reasons for the decrease in the forest and natural vegetation in the study area are over-cutting of forest trees due to the absence of the forest and natural vegetation preservation by the relevant authorities, and also the attempts of local people in this area to cultivate more lands in rural areas either for subsistence or to enhance their economic situation. The results of this study must draw attention of the relevant authorities to put urgent plans to preserve the remaining forest area, and also to put long-term strategies to restore the forest area that has been lost so far within the whole coastal region in general, and within the southern coastal basins in particular. Also, more studies on the impact of the war in Syria on land cover change as well as on the long-term implications of climate change must be carried out because the exact knowledge of spatial patterns and trends may help guiding sustainable development processes especially in the rural areas.

Acknowledgements

The study was supported by the Stipendium Hungaricum Programme.

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