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MAPPING OF MOSQUITO (*CULICIDAE*) BREEDING SITES USING PREDICTIVE GEOGRAPHIC INFORMATION METHODS

key words: mosquito, Culicidae, GIS, remote sensing, prediction

INTRODUCTION

In connection with the use of made by remote sensing for the mapping of mosquito (*Culicidae*) breeding sites, it is observable that the geographic information (GIS) methods, compared to others, are rarely applied to this field of study (partly because of the special conditions). In the use of aerial photographs for the mapping of mosquitoes (*Culicidae*) breeding sites, the application of image processing programs was dominant for a long time (e. g. Bourgeois, Caissie, 1997). However, the GIS technology also became conspicuous recently in this field. Relatively few papers have been written in connection with this topic (e. g. Srivastava *et al.*, 2001, 2003; Hausbeck 2004; Zou *et al.*, 2006; Schäfer, 2008). It is partly due to the fact that the prediction of the habitats of mosquitoes is extremely problematic with geographic information methods. The difficulty of this task is that those biotopes of smaller area must be determined which are shoal areas, but not every shoal, non-contributing depression acts as a breeding site.

The aim of our research was to create a model which determines the situation of the larval habitats of mosquitoes (*Culicidae*) with reliable predictions. The lack of this model appeared in terms of both basic research and practice.

The study area of our examination was designated in the area of Lake Tisza rich in varied mosquito habitats (*Culicidae*).

Our investigations were performed following two hypotheses: (1) the identifycation of breeding sites by the spectral analysis of remotely sensed data, (2) finding the relief forms acting like larval habitats.

METHODS

Sampling

In the field of research (the administrative area of Kisköre, Tiszanána, Sarud, Újlőrincfalva, Poroszló, Borsodivánka, Négyes, and Tiszavalk situating north from the levee, fig. 1.) [~362 square kilometres] the data collection on sampling points was carried out parallel to the designation of modelling study areas.

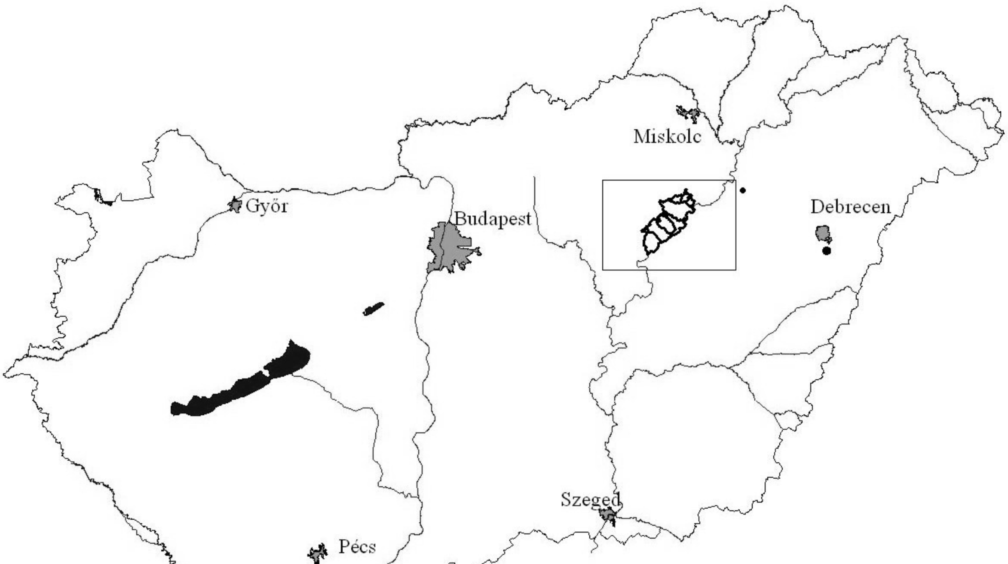

Fig. 1. Location of the study area. ***Source:** compiled by the authors.*

During the sampling, the following data were recorded: geographical coordinate; the water pH, temperature, depth, character (permanent or temporary) of the breeding sites; the rate of coverage and shadiness; the plant associations, the most characterristic aquatic, watersider and marshy plant species; presence/absence data and coverage of the pondweed vegetation; the water body type of the larval habitat; the determination of the habitat around the breeding site; the qualitative and quantitative features of the mosquito assemblages (*Culicidae*) developing in the studied habitats; larval density in the time of survey.

With this method, 563 samples were collected and analysed between 2006 and 2008.

Digital data

The aerial photographs of FÖMI (Institute of Geodesy, Cartography and Remote Sensing, Budapest), taken in 2005, were used. These were well useful for the examinations defined previously because (1) their time of taking does not significantly differ from the examination period; (2) depict the spring of the moist year, so they are applicable to estimate the size of the breeding sites with a certain relative-maximal extension; (3) their geometrical resolution (0.5 m) is the best available value.

The vector overlay made from the contour line of the M=1:10.000 topographic map (Institute of Geodesy, Cartography and Remote Sensing, Budapest) were applied to model the depressions as relief forms.

Determination of the study areas

The creation of polygons were carried out with GPS-survey, according to the EOV (Egységes Országos Vetület=Uniform National Projection System, common projecting system in Hungary) projection, with the use of M=1:10 000 topographic maps, RGB orthophotos, ArcGIS 9.1 (1999–2004) and ArcPad 7.0 (2000–2005) software. The size of the depicted breeding sites was represented with the maximum extension noticed during the survey (the extension of certain habitat patches has changed significantly during the examination period as well). 435 polygons got to the base map (the origin of the modelling). The relevant sampling data were added to the depicted patches.

GIS methods

IDRISI 15 Andes and SPRING (Camara et al., 1996) software were applied during the interpretation of the aerial photographs.

In the course of examination cluster analysis, isoclust (Iterative self-organising cluster) analysis and image segmentation were applied as not controlled classifycation methods. The applied controlled classification methods were the following: minimal distance, parallelepiped method, maximum likelihood (de Smith et al., 2008).

Rescaling with STRETCH method was used to emphasize the spectral ranges and manual photointerpretation was applied to depict the breeding area as additional methods.

Digital elevation models were made using IDRISI Andes. The surface analysis was carried out with IDRISI Andes, TAS and SAGA software. The plain areas and the depressions were selected with the IDRISI program.

RESULTS

During the improvement of the model mentioned previously in the introduction some hypotheses were confirmed but others had to be discarded. It was basic and general phenomena that the results showed regional differences, so some areas could be well classified but the larval habitats were hardly identifiable in certain cases.

Data processing based on spectral analysis

Cluster analysis

In the case of cluster analysis the result was dependent on the spectrum of the examined area and the homogeneity of the breeding sites. In fig. 2 an area segment is shown where the appearances of the breeding sites are all alike so the result also reflects the fact. The prediction is useful because the breeding sites were much smaller during field survey. Mainly it was due to the fact that the survey was in rainless years, but on the aerial photographs taken after rainy years (in the spring of 2005) due to the humidity conditions and the pattern of the vegetation the maximum extensions of the breeding sites could be seen. In a mainly arid, relatively homogenous pastures characterized by low grass, in spite of the small level differences the places of the characteristic water coverage (since they are also apparent as the border of vegetation) appeared clear-cut owing to the advantageous conditions of this segment. In the case of the area segment the results of the cluster analysis are better if the pixels less than 1% are left out and the method is carried out with broad classification.

In the area segments where the breeding sites were quite spectrally dispersed, even the broad classification did not yield suitable result.

These results of the cluster analysis contributed to the modelling, but they raised several problems in connection with the analysis of the spectrally dispersed area segments and in the visualization of the patches predicted as a breeding site, but not actually functioning like a site. These errors could be reduced by the narrowing of results: the estimations were carried out in the grasslands [arable lands and intensely anthropogenic areas (e. g. the built-up areas of settlements)] leaving the indifferent grounds for the development of mosquitoes out of consideration.

The result of the ISOCLUST method is quite similar to the ones mentioned above, but they were also different because of the iterative approach. Result is between the two (broad and fine) solution of the common cluster analysis was yielded. In the coarse solution the map made by this method was more detailed and in the fine solution it was more cleared.

Parallelepiped method

Using this method, we realized that the GPS data acquisition in the field during rainless periods, next to mainly arid breeding sites was not suitable for indicating study areas. For more accurate results study areas were determined by using the field survey as core area and correcting with aerial photos. Comparing the two analysis based on different study areas defined by separate methods, in every case of GPS determined (real) breeding sites used as study areas, the classification lacked the most clean-cut patches. The aerial photo data gathering improved the classification in most cases.

Minimum distance method

Even before our research the minimum distance method have been widely used, due to its quickness and relatively exact estimations (Richards, Jia, 1999). During the prediction analysis of mosquito breeding sites the results of this method were convincing and the data acquisition using aerial photos helped, too. Applying the field survey as study area_resulted only in patterns, while the aerial photo data gathering displayed the real area (fig. 3).

Maximum likelihood method

In this case the results were similar to the previous two directed classifying methods. The GPS field survey map resembled the parallelepiped method, while the aerial photo data gathering gave results parallel to the minimum distance method.

Stretching

The stretching of image values is one of the commonly used means of image processing (Szabó, 2006). Using this method, we had the opportunity to display the aerial photo emphasizing the breeding sites by the appropriate narrowing of the spectrum (fig. 4). The image was separated into RGB channels, and then the domain with the most contrast aspect of breeding sites was highlighted.

First, the appropriately changed values of the green channel were clustered, which yielded the best result, compared to previous images of the process. The really useful data are vectorial which could be placed on the topographic map. There was still too much clutter, so the interference was further reduced by applying a 7 × 7 modus filter (fig. 5). Then categories of breeding sites were removed by reclassifying, which was vectorizable (fig. 6).

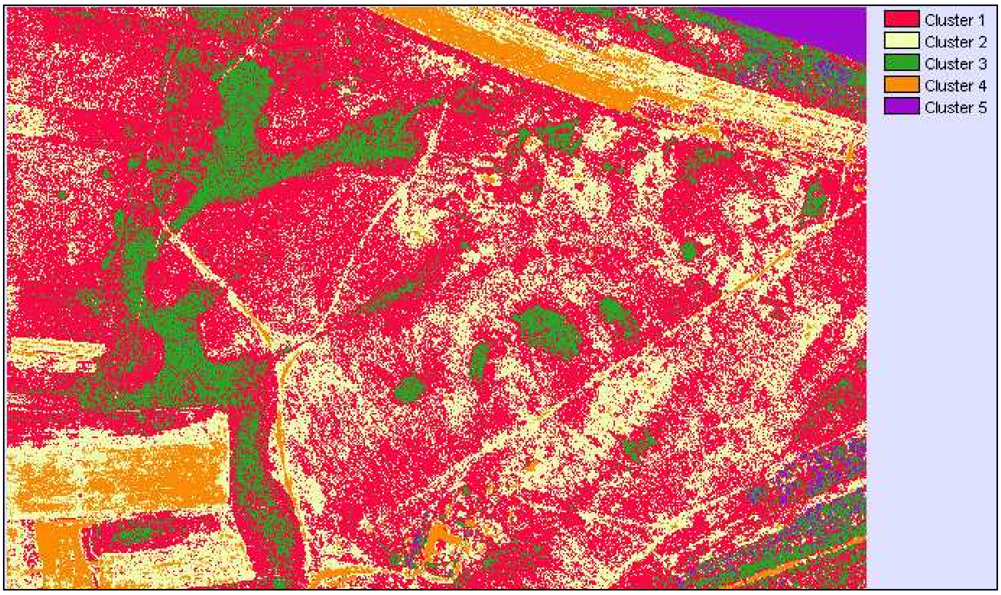

Fig. 2. Cluster analysis of the study area of Tiszavalk (broad classification) (predicted breeding sites: cluster 3). **Source:** *compiled by the authors.*

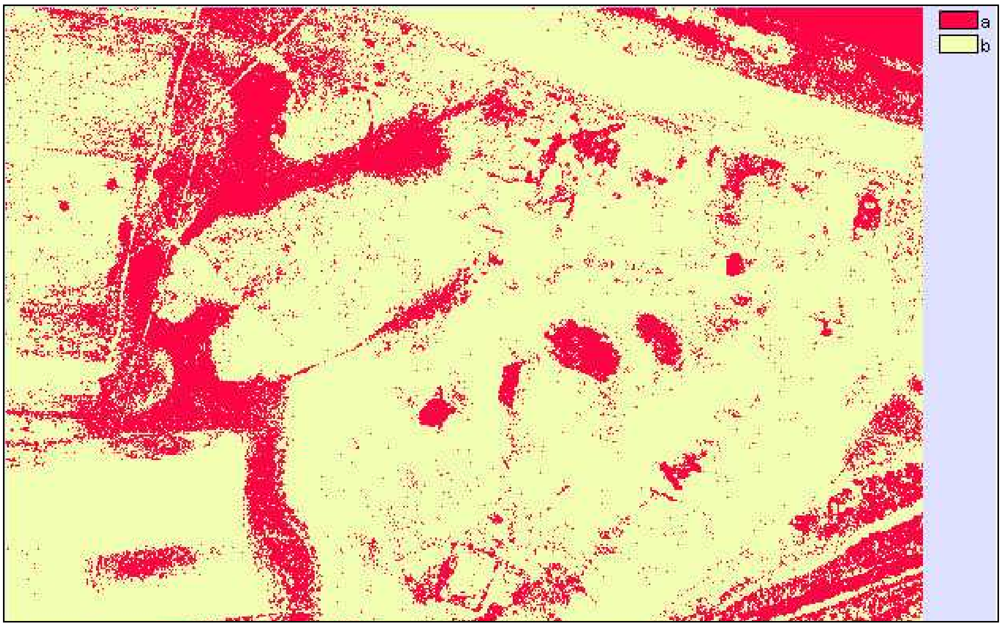

Fig. 3. Analysis of the study area of Tiszavalk with the minimum distance method, based on the study areas allocated by the GPS field survey and data collected from the RGB aerial photos (predicted breeding sites: a). ***Source:*** *compiled by the authors.*

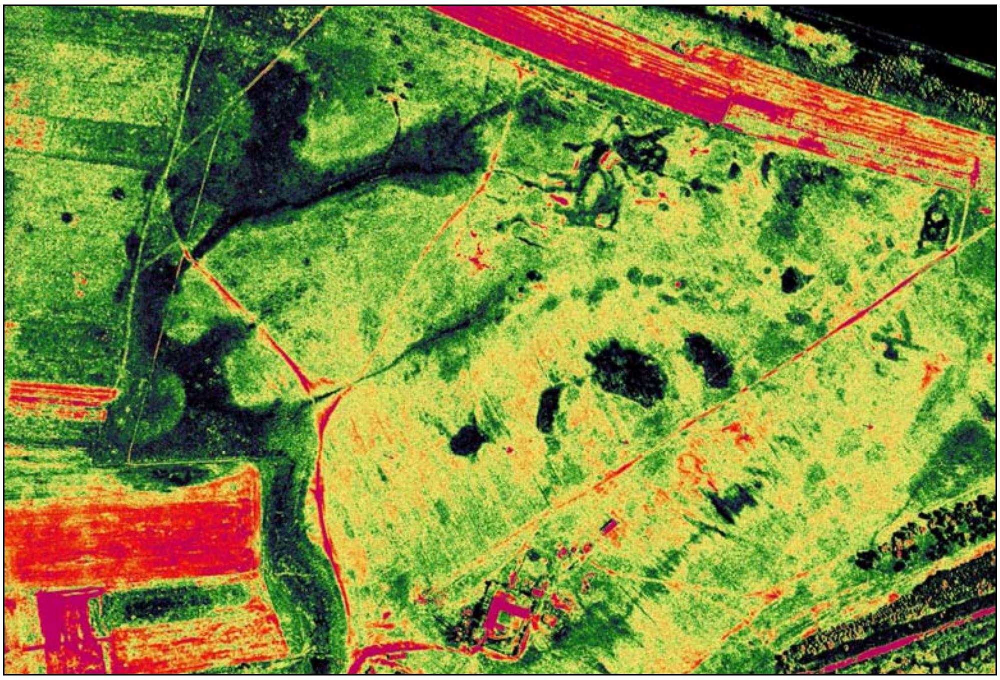

Fig 4. Stretched image of the study area of Tiszavalk. ***Source:*** *compiled by the authors.*

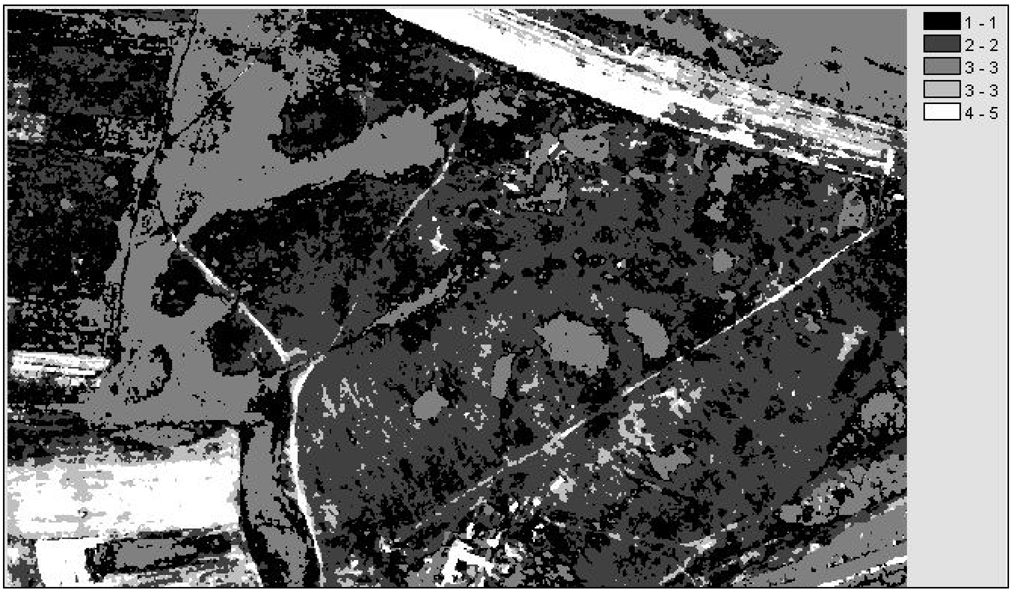

Fig. 5. Clustered and reduced data by applying a 7 × 7 modus filter of the study area of Tiszavalk (predicted breeding sites: 3 - 3). ***Source:*** *compiled by the authors.*

First, the appropriately changed values of the green channel were clustered, which yielded the best result, compared to previous images of the process. The really useful data are vectorial which could be placed on the topographic map. There was still too much clutter, so the interference was further reduced by applying a 7 × 7 modus filter (fig. 5). Then categories of breeding sites were removed by reclassifying, which was vectorizable (fig. 6).

This method yielded better results even with the less classifiable areas, than previously.

We found that this is the most suitable for developmental purposes, so it was used as the basis for processing. The aerial photos were separated into RGB channels, using the most informative green one the pixel values were stretched and the contrast-enhanced results were cluster analyzed. The stretching was quite an effective mean of visualising the most important breeding sites in representable range.

Image segmentation

Image segmentation results were the reverse of the previous ones. In the demonstrated area of Tiszavalk, it did not give better data, than the cluster analysis of stretched pixel intensity. However, the analysis of spectral dispersed area segments yielded the best solution compared to previous methods: no over-estimation of patches and low interference, which could be further reduced by applying filters (fig. 7).

Vectorization

Toward good utility the raster form created must be converted – preferably by automated means – to vector format. During the visualization of mosquito breeding sites on maps according to our present knowledge, the manual interpretation yields the best results, due to filtering out uncertainty created by automated methods.

Digital elevation model based study

Creating the digital elevation model, the first step was digitizing the elevation points, which lessened the lack of data in contour-less areas. In most cases, this was not enough, so more data points were input based on contour values and tags. For this, point-overlay was made using contour overlays and adding elevation points of the map, as well as specifying elevation points in places with depression (only where it was topographically justified, and only 20–40 cm deep points). Using this method resulted in a morphologically more accurate relief image (fig. 8).

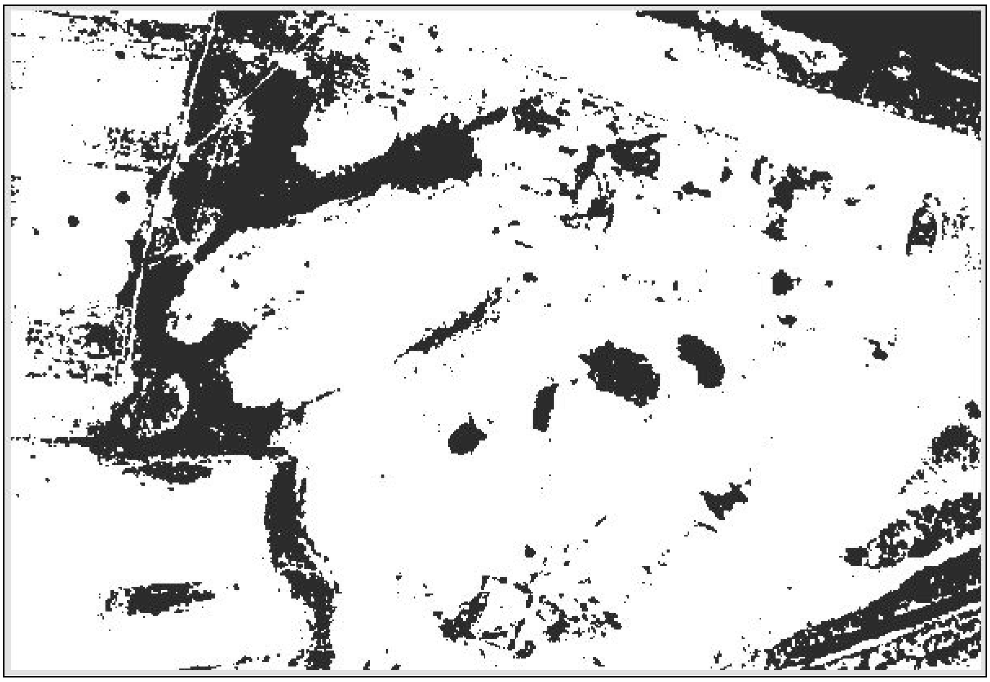

Fig. 6. Boolean layer of the reduced data (just the breeding sites confirmed by the prediction are visible). ***Source:*** *compiled by the authors.*

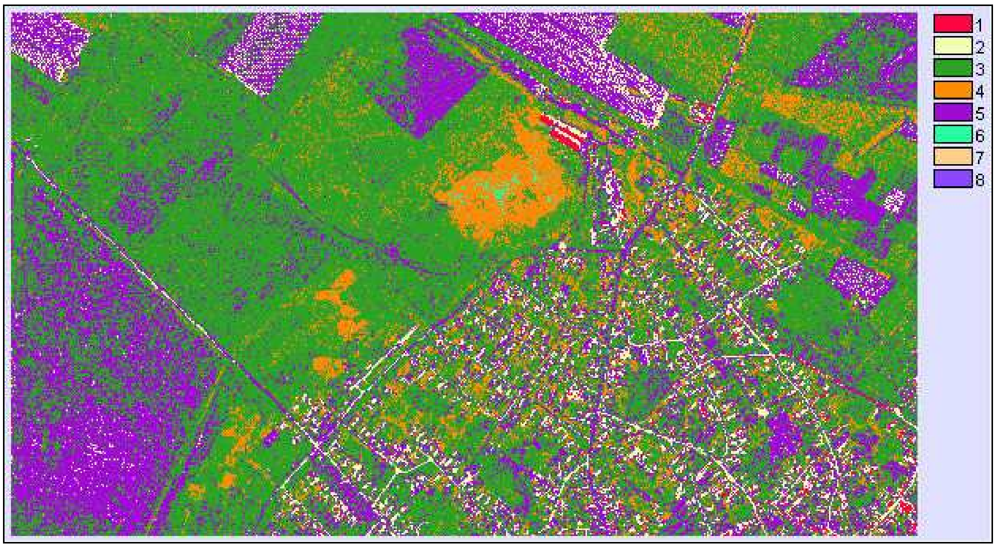

Fig. 7. Image segmentation of the study area of Poroszló (predicted breeding sites: 4, 6). ***Source:*** *compiled by the authors.*

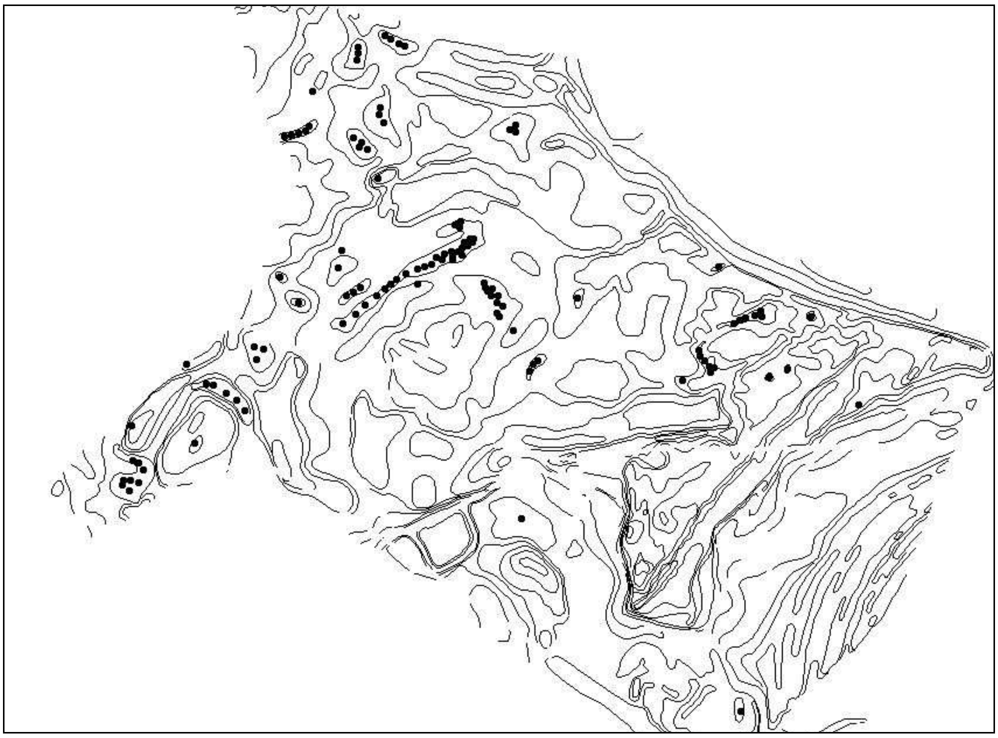

Fig. 8. Contour values of Tiszavalk and the other recorded spots. ***Source:*** *compiled by the authors.*

Fig. 9. Contour values of Tiszavalk with the depressions. ***Source:*** *compiled by the authors.*

In this study, 5 and 10 meter resolution models were used. In the case of the model created with the TIN technique the 5 meter resolution elevation model was possible, while kriging could be realised only with 10 meter resolution. This means that the smallest water-covered area was 25 and 100 square metres.

Using the digital elevation model for predicting mosquito breeding sites, we found that it could be used only with significant restrictions or not at all. The reasons are the following: (1) Currently in Hungary there is no contour-database which could be used to generate a precise elevation model with resolution suitable to represent the mosquito breeding sites. (2) In general the mosquito breeding sites of overriding importance are small relief-energy areas with only a few decimetre disparities. Using the digitized contours of the 1:10000 scale topographical maps is not sufficient: the 1 meter contour space have ±0.59m (Winkler, 2007), and the 5 meter resolution purchasable elevation model (HUNDEM-5) made from the contour-database have ±0.7-1.5 m (Iván, 2007) mean error. (3) To represent the mosquito breeding sites, 1 meter area resolution should be used, which is not realizable, only with very small areas. (4) The solution could be the high resolution elevation models made with laser technique (LIDAR), but there are only a few flight testing results, and the price is a significant restriction factor too.

Results of elevation model made by kriging

The method does not produce adequate relief models in the case of plain areas similar to the field of research. The slight elevation differences disappear by the levelling effect of interpolation. The search for depressions results in pixel-sized holes, which could be thought as clutter (fig. 9).

TIN model results

This method yielded good results with our sampling area, but only with rapid-change relief elements (the most of these are not breeding sites of overriding importance). This method does not level, with its triangulated irregular network from contour to contour (the angular points are the base, to be exact) it only yields correct results, where there are data (Jordán, 2007a, 2007b). To sum up, the TIN method can be used to identify bigger forms, which also could be indirectly done with spectral analysis due to their surplus moisture.

Fig. 10 (sampling area on the border of Poroszló and Tiszanána) shows the difference between the two relief-modelling methods (kriging and TIN). Kriging, as an interpolation method, results a model, which does not follow the change of relief in short distances. The TIN yields better results, if there is sufficient data. The depressions gained by kriging are larger, potentially flooded areas are more over-estimated than by the TIN model. In certain areas the two method's estimation are exactly the same. This is the consequence of the basic data being exactly the same, and where the data consistency was optimal too, the resulting relief forms were similar, leading to matching depressions.

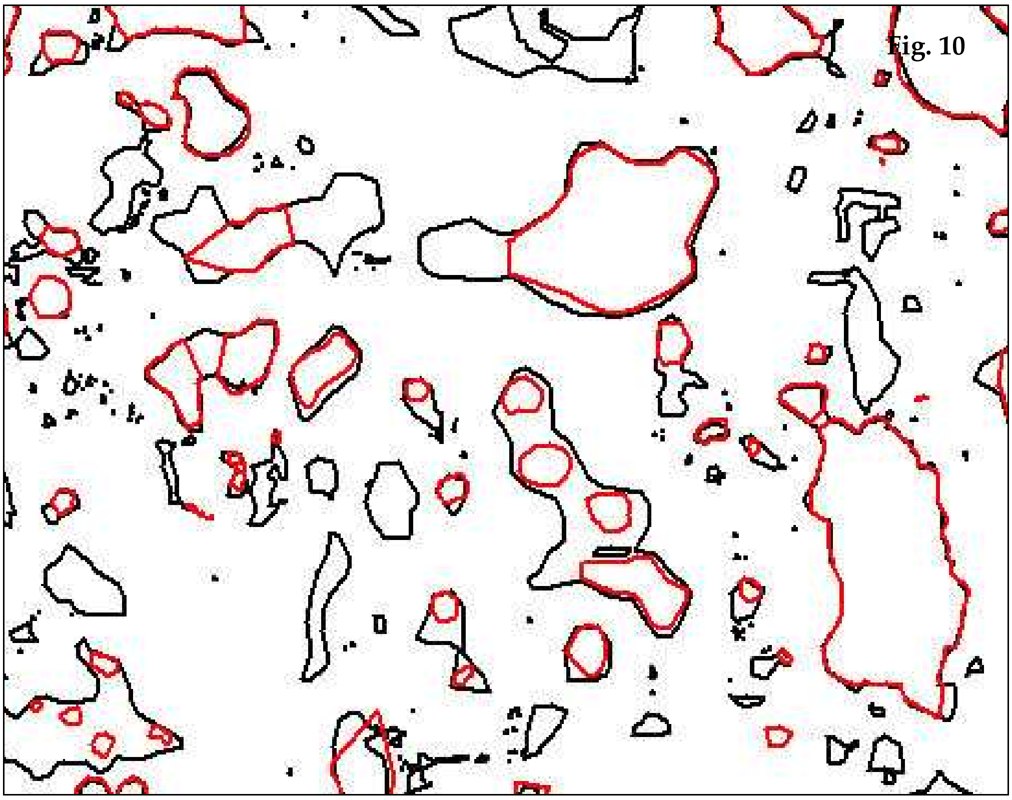

Fig. 10. Depressions of elevation models taken by different methods (black: kriging; red: TIN).
Source: *compiled by the authors.*

Testing the results of the predictive model

On the basis of the outcomes we found that the elevation model could not be used for predictive representation of the mosquito breeding sites, while the spectrum analysis yielded good results. Random predicted patches were verified using the same sampling method as the base survey. Even during the modelling procedures it became evident, that the best method is suitable for representing the marshy breeding sites and larger pits of meteoric water of the water-covered grasslands.

91 percent of the patches specified by the model turned out to be actual breeding sites. During the field controlling we found the causes of error, which caused the 9 percent deviation: (1) The spectrum analysis – due to the similar colour appearance of the relevant part of the RGB data – handles the shadows of groups of trees similar to permanent waters; (2) breeding sites of the size of a few square metres does not show up, or can not be distinguished from interference.

CONCLUSIONS

Summing up it can be proved that the spectral analysis yielded far better results in the predictive mapping of the mosquito (*Culicidae*) breeding sites than the elevation modelling. The spectral analysis resulted in the best: the grasslands were filtered from the applied data and the study areas sampled in detail were indicated (the collective use of GPS-surveys and the data acquisition from the aerial photos). Testing the different methods of spectral analysis in the entire field we stated that no automatic and generally utilizable method can be specified. The reason of this is that the field of study is extensive with extremely different area segments. In areas with homogeneous habitat structure, where the patches can be easily separated almost every method yields adequate results. The proper utility of the minimum distance method belonging to the controlled classification can be enhanced. The best result can be produced in the areas with homogeneous habitat structure, if adequate methods are used for the area segments based on the previous examinations. The predictive method does not indicate the very small (a few square metres or narrow like a strip) breeding sites and it is suitable for the determination of the map localisation of the marshy breeding sites and the pits of meteoric water, especially in grasslands. With the utilization of infrared aerial photo series, the same method is applicable for the examination of the breeding sites belonging to the previous type in habitats covered by tree vegetation (e. g. flood plains, forests).

The errors of the model made from the RGB aerial photo under the margin of 10 percent can be mostly corrected by using infra-coloured (IR) aerial photo, so the precision can also be increased in areas not covered by tree vegetation. Examples of the utility of IR aerial and satellite images are found in the scientific literature: Hay et al. 1998, Thomas & Lindsay (2000) and Lacaux et al. (2007). After the finish of the MADOP 2007 (Digital Orthophoto Program of Hungary) the IR aerial photo data of the entire country are available. Recently the hyperspectral remote sensing is a promising technology which can be aerial flight data acquisition or the result of satellite recording (e. g. MODIS satellite, which records data every day from global surface in 36 channels, the access is free, but the resolution is 250 m and it is not suitable for our aim). But in the light of the recent fields of application and results

(Jung 2005; Hargitai et al., 2006; Nagy et al., 2007; Bakos, 2008; Burai et al., 2008; Milics et al., 2008) the aerial flight use of hyperspectral sensors at optimal time can open new prospects in the mapping of the mosquito (*Culicidae*) breeding sites as well. The previously mentioned data's suitability for prediction and its cost/benefit ratio need to be examined.

The real importance of the spectral analysis's success lies in its use for the objective designation of mosquito-control areas and for making the actualization of these designations quicker. This method both accelerates the mapping process and yields results more precise.

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SUMMARY

Application of remote sensing and other GIS methods in the subject of mapping mosquito breeding sites has not been premised accordingly. Despite the facts that the duration of field surveys would be shortened and the effectiveness of action plans would be higher with the supportance of computer modelling techniques. This work aimed to evaluate the applicability of digital elevation models and aerial photographs in the prediction of mosquito breeding sites. Relief analysis was carried out seeking depressions based on elevation models created with TIN and kriging interpolation methods. Spectral analysis was performed on aerial photographs to identify the patches of higher water content or moisture. The results show that terrain analysis can not give acceptable results due to its resolution and accuracy. Spectral analysis of normal (visible range) photographs can be a useful tool in predicting of breeding sites. On grasslands the verificitaion revealed 91% correct results.