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IDENTIFICATION OF INLAND-EXCESS WATER PATCHES BASED ON LiDAR AND SENTINEL 1 DATA

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Abstract

Understanding the habitat is essential for economic production. As a result of rapidly changing processes, features of habitats may be modified, it may be affected by a wide variety of factors. Inundation caused by inland-excess water (IEW) is one of the most significant natural disasters but spatial and temporal targeting of it is also a problem in practice. Over half of Hungary's territory is endangered by IEW. For the development of inland-excess waters a combination of several adverse natural and human activity is highly important. The formation of IEW is primarily determined by meteorological, soil and terrain conditions. During the research, the causes of the development of IEW were analysed based on the terrain conditions of the area in a grassland. Soil connections have been well explored according to the other studies, but not as terrain causes. Therefore the applicability of digital elevation models based on remote sensing (high density LiDAR) data and Sentinel 1 data in inland areas is a priority area of our research. To examine the relief, elevation data of conventional analog topographic maps with 1:10000 scale and an aerial LiDAR data were compared. Sentinel 1 data were used to validate the results based on the LiDAR data.

Based on digital elevation model (DEM) derived from topographical map shows that there is no risk of IEW on the grassland. It is, however, contradicted by the reality, the inland marshes presents on grassland land during on-site visits and which can be identified by the LiDAR and Sentinel 1 images.

Key words: inland - excess water (IEW), LiDAR, DEM, Sentinel 1, SAR

INTRODUCTION

Inland-excess water bodies are globally threatened by ongoing urbanization, agricultural irrigation, environmental degradation and climate change (Vörösmarty et al., 2010). Due to the climate change, extreme water management situations (for instance inland-excess water) are a growing challenge, which are concern in agricultural production not only worldwide but in Europe and in Hungary. Currently, predictability of weather is uncertain, resulting from increasingly variable weather conditions (Juhász et al., 2020). The spatial and temporal limitation of IEW is a major task of the examinations of these phenomenon.

Inland-excess water is a form of surplus surface water, often regarded as a specific flood type (Bozán et.al, 2018). Surplus water is a specific hydrological type on flat areas, which is especially important in Hungary, since more than the half of the country (45.000 km^2) is flat area and 60 %,

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more than 4 million hectares is imperiled by IEW. IEW retention is a typical management problem of low relief plains (Darboux, Huang, 2005; Pásztor et al., 2006). Retention in these lowlands is caused by a precipitation surplus, combined with blocked drainage or impeded infiltration, and low soil water storage capacity and infiltration rates. The consequences of inland-excess water retention are soil degradation and crop loss; therefore, it is one of the greatest environmental hazards in Hungary.

Mapping of the IEW hazard is a great challenge because the formation of IEW inundation is a complex process (Bozán et.al., 2018). Decades ago, IEW vulnerability areas on plain catchment areas were surveyed by traditionally methods, but nowadays, modern remote sensing and GIS technologies are commercially available for accurate measure the mezo and microrelief conditions (Tamás et al., 2019; Goulden, 2014).

The use of remote sensing and photogrammetry have been found in the studies of identification of open water region (McFeeters, 1996). According to Bach et al., 2000, digital elevation models (DEM) can be use to evaluate geomorphological forms, however accurate digital elevation model not available to charachterize inland-excess water area in Hungary (Pásztor et al., 2006).

The above-mentioned problems can be eliminated by combining remote sensing data such as LiDAR and SAR data as Sentinel 1 (Gálya et al., 2018) and, using these technologies is a good solution to monitor IEW patches, against intensive and extremely time demanding in situ surveys. LiDAR is an active sensor which is a relatively new technology which enables collecting directly 3D data very fast (Demelezi et al., 2019; Canaz et al., 2015; Tamás et al., 2019).

In this study, LiDAR data were used to analyze IEW patches, and to validate the results Sentinel 1 data were used. With the increasing availability of Synthetic Aperture Radar (SAR) imagery with higher temporal and spatial resolutions, a wide variety of approaches have been developed to extract water surface from SAR imagery (Liang, Liu, 2020). The traditional surveys of hydrological situations are increasingly being supplemented by the analysis of satellite imagery, which plays an important role in the Copernicus program (Westerhoff, 2013). One of the most up-to-date radar applications is (satellite) radar interferometry. By this method, the earth's surface can be seen in very small magnitudes (even millimeters), vertical displacements. Extensive surveys allow any part of the Earth to be applied, cost-effective and time-efficient (no fieldwork required). It can be used to predict natural disasters. The European Space Agency (ESA), within the framework of the Copernicus Program, has undertaken to develop the European Radar Observatory, which includes the development of service and application of two satellite SAR systems. One possible solution could be to monitor the inland-excess water using microwave remote sensing (Ruiz et al., 2012). Micro-wave remote sensing equipped with SAR system, because of their exclusive cloud, rain and haze penetration capacity, offers a primary tool for real-time assessment of flooded areas (Rahman, Thakur, 2018). One the most important advantage of using SAR data is that land and water contrast can be easily distinguished (Dewan et al., 2006).

The aim of the research was to analyze of the accumulation and run-off conditions of inland-excess water applying soil, different digital elevation models (traditional and LiDAR based) and Sentinel 1 data. One of the possible solutions could be the evaluation of LiDAR data and radar images for the monitoring of inland-excess water and the characterization of their occurrence risk. Based on the results, the IEW can be more clearly defined with LiDAR laser densitiy values and spatial segmentation of Sentinel 1 images, and it could help in water management planning of an agricultural area.

MATERIAL AND METHOD

Location of the sample area

One of the objectives was to assess the run-off and accumulation processes of inland-excess water based on different digital elevation models derived from conventional topographic maps, LiDAR and SENTINEL 1 remote sensing data. The reference areas was a grassland of 15.6 hectares at the Northern Eastern part of Hungary. Figure 1 shows the location of sample area.

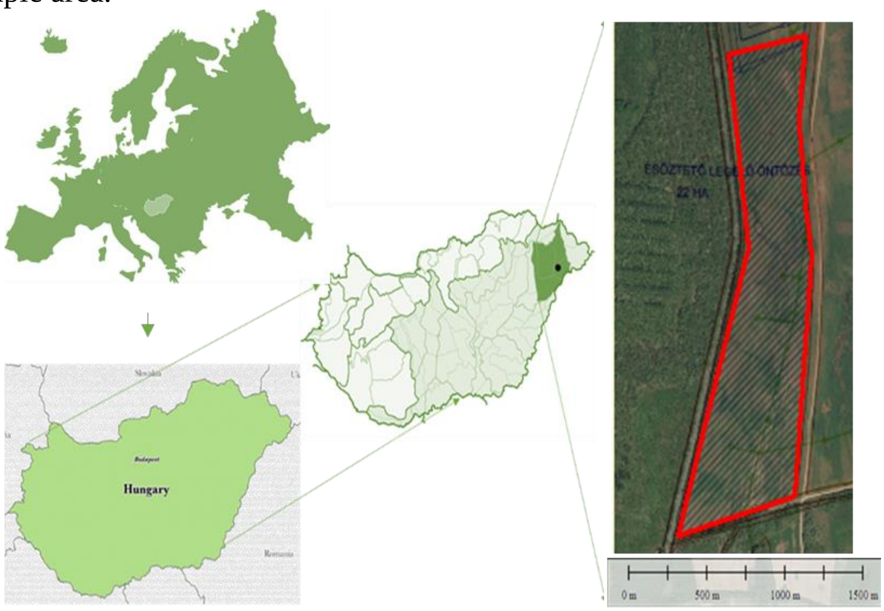

Fig. 1: Location of the sample area

Detection of IEW areas using digital elevation models from different sources.

In the case of DEM generated from analogue basic data the processing steps were the followings: scanning the conventional topographical paper map at a resolution of 600 dpi and transforming it into EOV projection. Subsequently, vector layer has been created and on the basis of topographical map contour lines have been digitalised. Then database has been compiled with height data. A total of 25,372 vertex points representing height data have been input and 3D contour surface was generated using kriging method. On the basis of the elevation model, the areas susceptible to inland-excess water was marked.

Detection of IEW areas from digital elevation model of LiDAR data

The aerial LiDAR survey arising from cooperation between Institute of Water and Environmental Management and Eurosense Ltd. Laser scan survey was carried out using IGI LiteMapper system. The grassland was surveyed with the lowest vegetation. The combination of the resulted appropriate factors provided a good opportunity to understand topography of areas and evaluate differences in micro-relief. The area was made up of in a total of 129,072,937 points. The resolution of LiDAR data points is 14.58 point/km^2 thus it can be used to build high resolution models. The laser point cloud processed by photogrammetry was pre-processed with GlobalMapper software. A preliminary elevation profile analysis was carried out in the software for the grassland.

On the basis of LiDAR images, the maps of slope categories was prepared and finally the inland marshes located was marked in the sample area. Elevation model based on high-resolution LiDAR data was analysed using similar steps as for processing DEM based on analogue (so-called traditional) data. Then, the roads, canals and reservoirs were sorted out. During the next phase, the run-off and accumulation relations were investigated on the basis of slope conditions. After this, the intensity values were examined of the laser survey to map the inland-excess water. In the next step, the applicability of digital elevation models were compared based on two different types of mapping, traditional and LiDAR images, for mapping IEW.

Validation of IEW based on Sentinel 1 data

Sentinel 1 data were downloaded about the area of the grassland from the website of European Space Agency (ESA) (https://scihub.copernicus.eu/). During my research work, radar image (amplitude values) was processed in ESA Sentinel Application Platform (SNAP) 2.0 software environment. As a first step of the pre-processing, the radiometric calibration of the images were made where the polarisation intended to be processed to got the Sigma0_VV channel and a single product speckle filtering. It was followed by a geometric correction (range doppler terrain correction). Finally, a binary transformation has been carried out. The histogram showed the reflectance displayed on a logarithmic scale. Low values correspond to water while high values show non-water areas. On the basis of the histogram a threshold were determined to separate water from the land. This threshold was 2.21E-2.

During segmentation the following formula was used:

$$255 * (Sigma0\_VV < 2.21E-2)$$

The expression Sigma0_VV <2.21E-2 is interpreted as logical value. Values less than 2.21E-2 are true (represented with 1) while values higher than that are false (represented with 0).

RESULTS AND DISCUSSION

Firstly, the results were presented in which evaluated the causes of formation of IEW patches based on the runoff, relief conditions. Figure 2 shows the identified inland-excess water patches based on the topographical map and LiDAR map on the grassland.

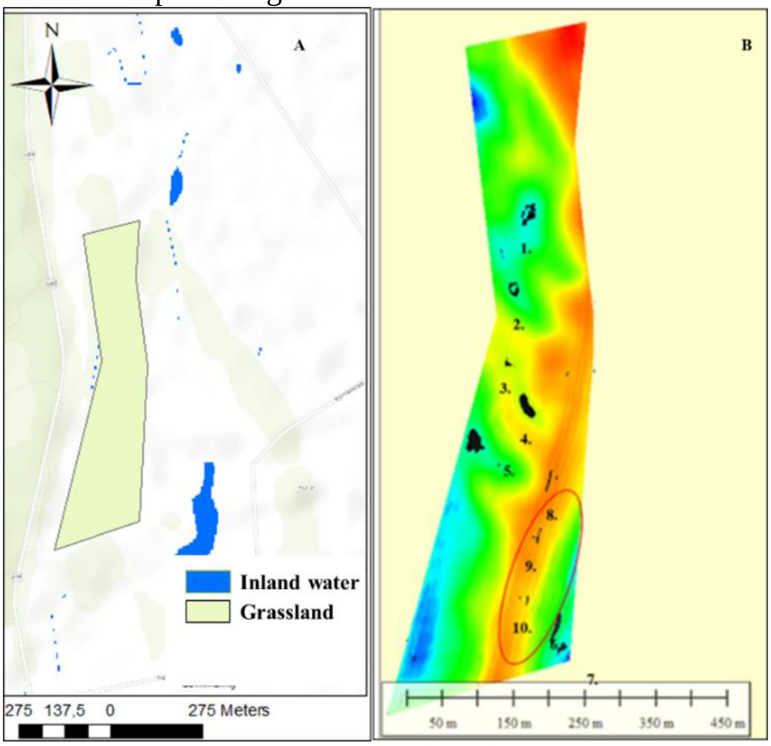

Fig. 2: Location of inland-excess water patches

A- Based on the digital elevation model derived from 1:10000 topographic map

B- Based on LiDAR

For the grassland, there were no inland-excess water patches based on the topographical map (Figure 2/A.). However, 10 inland-excess water patches were indentified based on the LiDAR (Figure 2/B.). Based on these information, the IEW patches were selected by the natural and antopogenic factors. The 1.,2.,3.,4.,5.,6.,7. patches located in areas of lower relief (152,24-154.88 m),in these case the formation of IEW was casued by the relief, because in areas with lower relief, inland-excess water accumulates.

The DEM produced from the digitization of analog data and the aerial LiDAR were subjected to a comparative analysis on the relief of grassland (Figure 3).

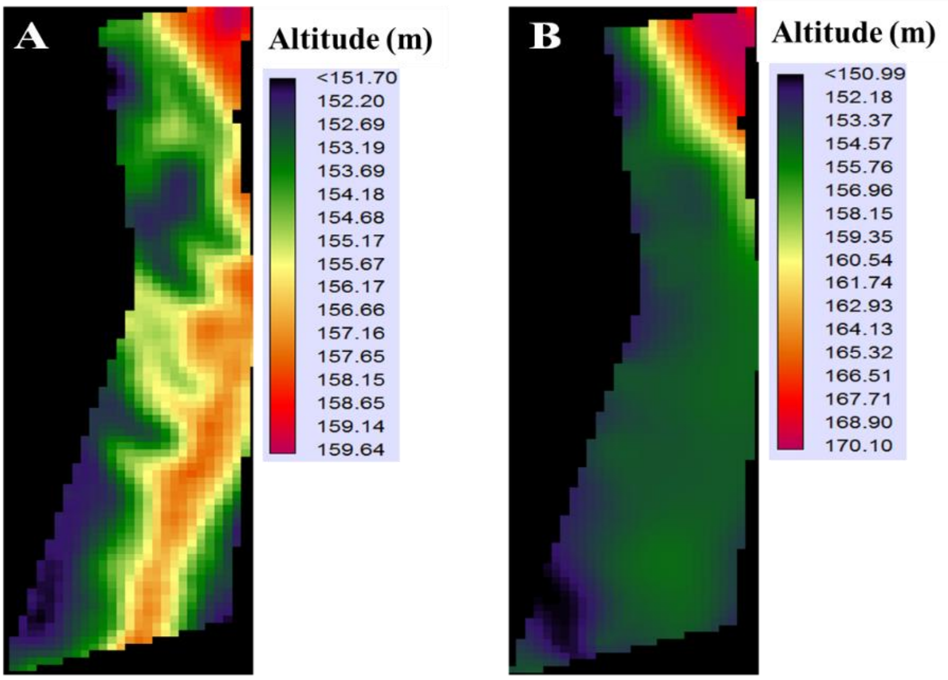

Fig. 3: Elevation values based on 10x10 m spatial resolution databases
A – Relief map from LiDAR data; B – Relief map from topographical map

The results calculated based on the 1:10000 scale topographical map show that solely based on elevation of grassland lack risk of inland-excess water. It is, however, contradicted by the inland marshes seen on grassland during on-site visits and which can be marked on the aerial laser images. This can be explained in part by soil and hydrological characteristics and the 10 meters resolution of the elevation model by which the micro relief changes can be monitored to a limited extent.

The height difference of the area is 7,94 m due to laser data while conventional DEM (obtained by digitising analogue basic data) showed 19,11 m. The major difference is the lack of pattern of the higher part running lengthwise along the area and the erosion running in the direction of the slope on conventional DEM (obtained by digitising analogue basic data) (Figure 4/A). Schumann et. al., 2008, compared digital terrain models based on LiDAR, contour line map, and SRTM for hydrological modeling. Based on their results, they determined that the DEM based on LiDAR was the best, followed by the SRTM and then the DEM based on contour lines/traditional maps. The DEM and the slope category map of the grassland are shown in Figure 4.

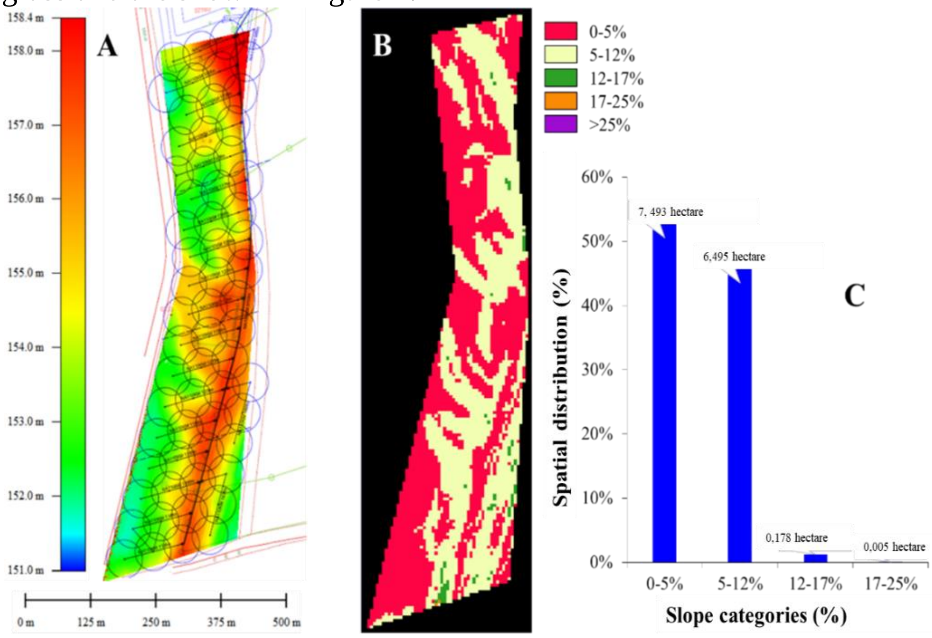

Fig.4 Terrain model (A) and slope categories (B and C) of the studied grassland

The Figure 4/B shows that the area is crossed lengthwise by a hill almost in half significantly determining the run-off and accumulation of precipitation on the surface. The hill rises from the lowest spot of the area to a height of 5 meters and this elevation of the relief serves as a catchment border. The runoff vectors show the direction of runoff water. The accumulation points were marked in the area using these vectors. Accumulation lines representing surface runoff also helped (Figure 5/A). Figure 5/B shows the runoff vectors, which actually show the orientation of the water.

On the basis of the runoff lines,we concluded that the deeper accumulation cauldrons could pool water as a result of high-intensity precipitation or snowmelt, hence, the intensity values of the laser survey were analyzed. Since airborne LiDAR system used infrared wavelength range for measurements, it can be suitable for mapping the potentially harmful excess surface water (Figure 6).

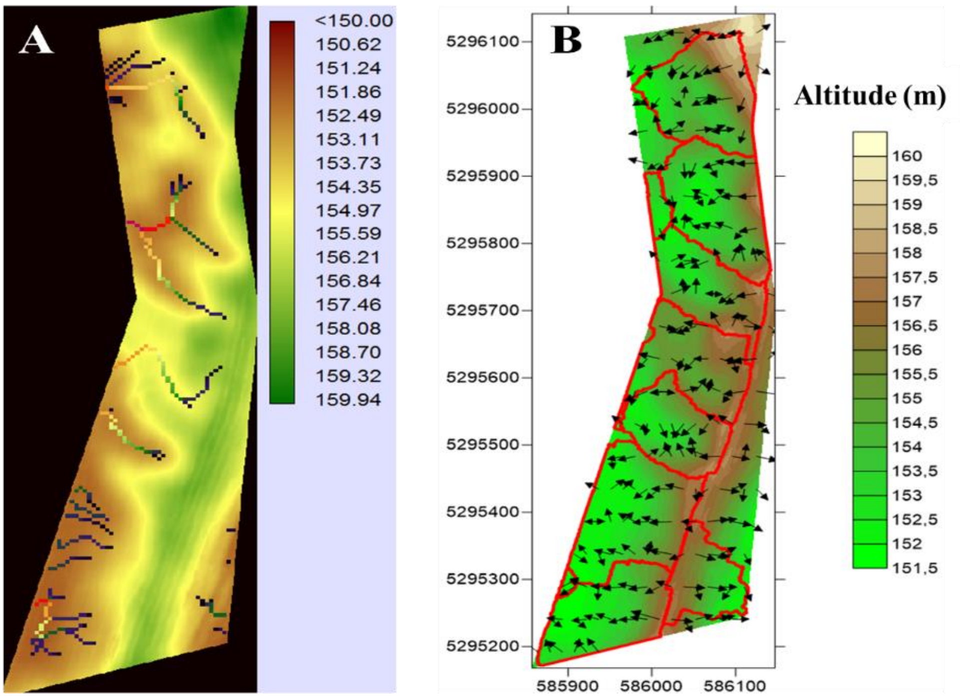

Fig. 5: Digital elevation model with runoff vectors (A), and water catchments (B)

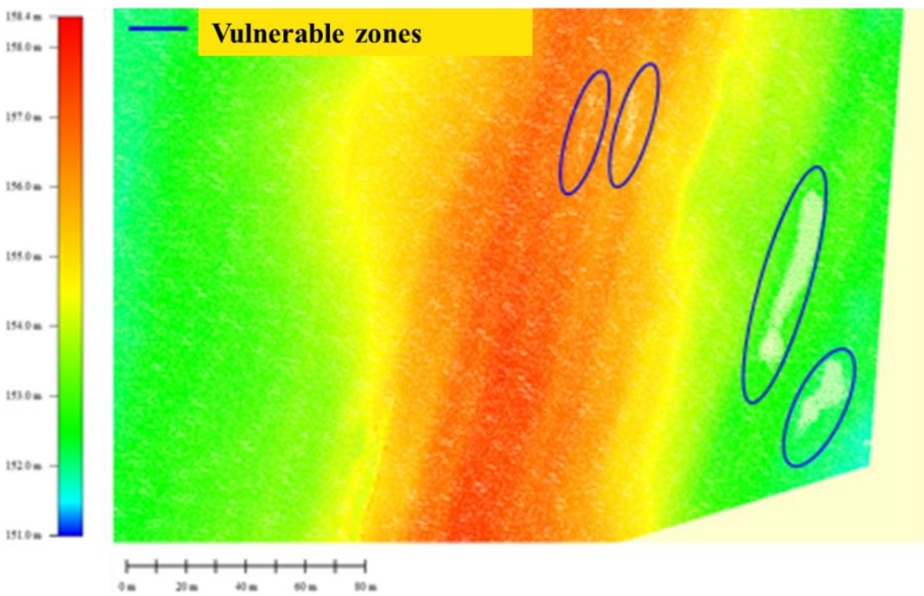

Fig. 6: Areas with less frequent point densities in laser point cloud, indicating the vulnerable zones of IEW

During the selection of intensity values I identified 45 pieces of harmful inland-excess water on the area, representing almost 0.2 ha (Figure

7/A, B). Among the areas some have been wrongly classified in a given category during the sorting procedure (it concerns mainly the southern areas with a size of less than 15 m^2) (Figure 7/C and D) because the point density was higher. Sorted these areas, only 13 pieces of larger and coherent area affected by inland-excess water could be found of which more than half were less than 100 m^2, while the size of the largest inland marsh was 512,5m^2.

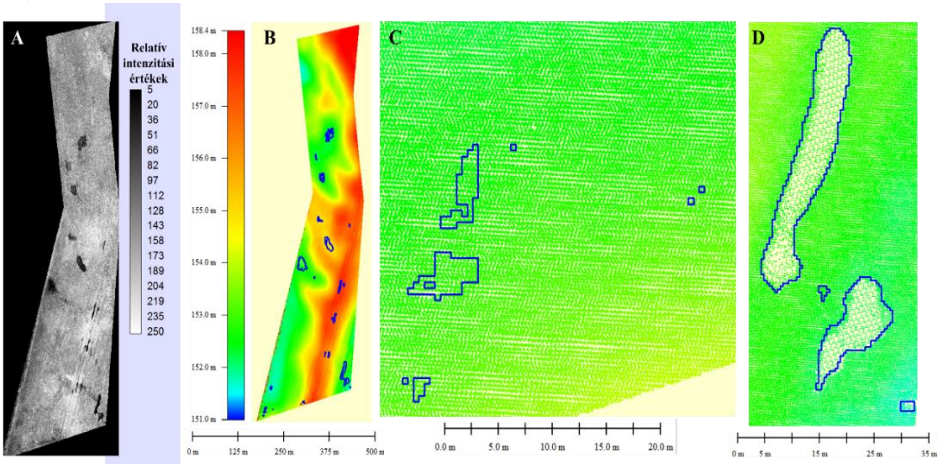

Fig. 7: The map generated based on the reflected laser intensity (A), the inland water map made as a result of the sorting procedure (B) and the inland marshes sorted with errors (C) and appropriately (D)

Thomas et al., 2017, examined hydrological sensitive areas based on digital elevation models. Their results showed that the best resolution is 1-2 m to analyse microtopography. Yang et al., 2014, investigated the impact of a digital elevation model based on LiDAR on large-scale river basin modeling. Their results showed that in hydrological situations could be better using DEM derived from high-resolution LiDAR. During our research, Sentinel 1 data were used to validate IEW areas (Figure 8).

Figure 8 shows a laser-based bitmap of the area and the Sentinel 1 satellite image. Based on Sentinel data, inland-excess water patches (5., 6., 7.) were validated. However, in case of other patches were not exact match, probably due to the 10 m resolution of Sentinel 1 data.

The results of our studies coincide with the authors emphasizing the dominant role of topography.

CONCLUSIONS

Based on the DEM derived from LiDAR, inland - excess water patches were analysed using laser intensity values, the same as the number and location of the patches during the filed survey. Based on our results, found that the primary cause of the formation of IEW was topography and runoff factors.

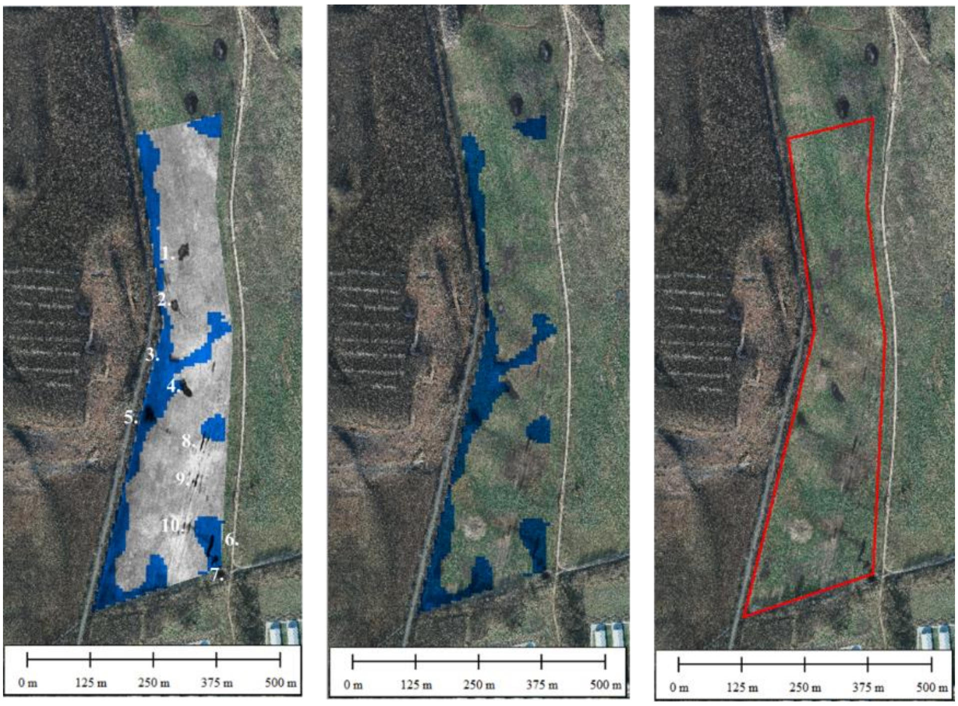

Fig. 8**:** Validate IEW areas based on Sentinel 1 data

Based on LiDAR survey, the microtopographycal differences can be monitored, because based the relief and runoff maps obtained more accurate, heterogeneous, however the resolution was 10 x 10 m.

Summary, based on our results, found that the primary cause of the formation of inland - excess water was topography and runoff factors.

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REFERENCES

1. Bach E., Peter C., Stuart N. 2000, Modelling river floodplain inundation with high resolution digital elevation models. 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Problems, Prospects and Research Needs. Banff, Alberta, Canada. September 2-8, pp.10-15.
2. Bozán Cs., Takács K., Körösparti J., Laborczi A., Túri N., Pásztor L., 2018, Integrated spatial assessment of inland excess water hazard on the Great Hungarian Plain. Land Degradation & Development. Vol. 29. Issue 12.pp. 20-30.

3. Canaz S., Karsli F., Guneroglu A., Dihkan M. 2015, Automatic boundary extraction of inland water bodies using LiDAR data. Ocean & Coastal Management, 118, pp. 158–166.
4. Darboux F., Huang C., 2005, Does soil surface roughness increase or decrease water and particle transfers? Soil. Sci. Soc. Am. J. 69. pp 748-756.
5. Demelezi F., Nagy A., Gálya B., Tamás J., 2019, Evaluation of soil water management properties based on LiDAR data and soil analyses at farm level. Natural Resources And Sustainable Development 9 : 2 pp. 160-173.
6. Dewan A.M., Kankam - Yeboah K., Nishigaky A., 2006, Using synthetic aperture radar (SAR) data for mapping river water flooding in an urban landscape: a case study of greater Dhaka, Bangladesh. J. Jpn. Coc. Hydrol. Water Resource. 19 (1), pp 44-45.
7. Gálya B., Blaskó L., Nagy A., Juhász C., Riczu P., Tamás J., 2018, Spatial segmentation of inland water surface using C-band synthetic aperture radar images on the Great Hungarian Plain. In: Geophysical Research Abstracts / EGU General Assembly 2018, EGU General Assembly, pp. 552.
8. Goulden T., Hopkinson C., Jamieson R., Sterling S., 2014, Sensitivity of watershed attributes to spatial resolution and interpolation method of LiDAR DEMs In three distinct landscapes. Water Resour. Res. 50, pp 1908-1927.
9. Juhász Cs., Gálya B., Kovács E., Nagy A, Tamás J., Huzsvai L., 2020, Seasonal predictability of weather and crop yield in regions of Central European continental climate. Computers and Electronics in Agriculture Volume 173, pp. 30.
10. Liang J., Liu D., 2020, A local thresholding approach to flood water delineation using Sentinel-1 SAR imagery. ISPRS Journal of Photogrammetry and Remote Sensing, 159, 53–62. doi:10.1016/j.isprsjprs.2019.10.017
11. McFeeters S.K., 1996, The use of Normalized Difference Water Index (NDWI) in the delineation of open water features. Int. J. Rem. Sens. 17(7), pp 1425-1432.
12. Pásztor L., Pálfai I., Bozán Cs., Kőrösparti, J., Szabó J., Bakacsi Zs., Kuti L., 2006, Spatial stochastic modelling of inland inundation hazard. 9th AGILE Conference on GIS, Visegrád, pp. 139-143
13. Rahman M.R., Thakur P.K., 2018, Detecting, mapping and analysing of flood water propagation using synthetic aperture radar (SAR) satellite data and GIS: A case study from the Kendrapara District of Orissa State of India. The Egyptian Journal of Remote Sensing and Space Science, 21, pp S37–S41.
14. Ruiz A.M., Sousa J., Hanssen R.F., Avilés M., 2012, Application of SAR interferometry for land subsidence monitoring. Conference Book. Jaén. Spain. 25
15. Schumann G., Matgena P., Cutler M.E.J., Black A., Hoffmanna L., Pfister L., 2008, Comparison of remotely sensed water stages from LiDAR, topographic contours and SRTM. ISPRS Journal of Photogrammetry and Remote Sensing. Vol .63. Iss.3, pp 283-296.
16. Tamás J., Juhász Cs., Zsembeli J., Petis M., Nagy A., 2019, In: XIII. International Symposium on Plant Irrigation for Sustainable Rural Development Bydgoszcz, Poland pp. 23-24.
17. Tamás J., Kiss N.É., Riczu P., Gálya B., Budayné-Bódi E., Gross M., Nagy A., 2019, Application of LIDAR technology in cattle grazing areas. Natural Resources And Sustainable Development 9(2) pp. 106-112.
18. Thomas L.A., Jordan P., Shine O, Fenton O., Mellander E., Dunlop P., 2017, Defining optimal DEM resolution and point densities for modelling hydrologically sensitive areas in agricultural catchments dominated by microtopography. International Journal of Applied Earth Observation and Geoinformation, pp 38-52.

19. Vörösmarty C.J., McIntyre P.B., Gessner M.O., Dudgeon D., Prusevich A., Green P., 2010, Rivers in crisis: global water insecurity for humans and biodiversity. Nature 467, pp. 555–561.
20. Westerhoff R.S., Kleuskens M.P.H., Winsemius H.C., Huizinga H.J., Brakenridge G.R., Bishop C., 2013, Automated global water mapping based on wide-swath orbital synthetic-aperture radar. Hydrology and Earth System Sciences. 17, pp. 651-653.
21. Yang P., Ames, D.P., Fonesca A., Anderson D., Shrestha R., Glenn N.F., Cao Y., 2014, What is the effect of LiDAR-derived DEM resolution of large-scale watershed model results? Environmental Modelling & Software, 58. pp. 48-57.

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