FLOOD PREDICTION BASED ON A DIGITAL ELEVATION MODEL CREATED BY UNMANNED AERIAL VEHICLE

PREDIKCIJA POPLAVA NA OSNOVU DIGITALNOG MODELA VISINA KREIRANOG SNIMANJEM BESPILOTNOM LETELICOM

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Summary: Water is the greatest natural treasure of Serbia. However, this natural treasure is not only for the benefit of the citizens, but it has caused and continues to cause the greatest natural disasters with significant material damage in the country. This paper deals with the methodology of using an unmanned aerial vehicle with an integrated RTK GNSS module, for the purpose of field surveilance by Unmanned Aerial Vehicle (UAV) photogrammetry. Gradually and in detail, the procedures are explained, as well as the use of programs for processing Pix4D, Global Mapper and creating 3D terrain models. A control and presentation of obtained resuls is performed. Based on digital elevation models, for the research area, a flood zone simulation for different levels of the Tisa River is presented.

Keywords: Water, UAV photogrammetry, 3D terrain model

Rezime: Voda je najveće prirodno blago Srbije. Međutim, ovo prirodno blago nije samo u korist građana, nego je izazivalo i izaziva najveće prirodne katastrofe sa značajnom materijalnom štetom u državi. U ovom radu obrađena je metodologija upotrebe bespilotne letelice sa integrisanim RTK GNSS modulom, za potrebe snimanje terena metodom Unmanned Aerial Vehicle (UAV) fotogrametrije. Postupno i detaljno su objašnjeni postupci rada, kao i upotreba programa za obradu Pix4D, Global Mapper i kreiranje 3D modela terena. Urađena je kontrola i prikaz postignutih rezultata. Na osnovu digitalnih modela visina, za područje istraživanja, prikazana je simulacija poplava za različite nivoe reke Tise.

Ključne reči: Voda, UAV fotogrametrija, 3D model terena

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1. INTRODUCTION

Nowadays, in connection with undesirable water phenomena, it is necessary to deal with water management issues, which, among other things, include flood check, river regulation, riverbed maintenance, internal drainage, coastal insurance, etc. In order to protect the citizens, it is becoming increasingly important to invest in resolving the situation of floods and inland waters in endangered areas. However, the construction of flood embankments is only one of the possible answers. With the development of technology, new solutions that are fast and support effective protection can be presented to decision makers, which would significantly improve emergency prevention procedures. In addition to the technical and technological development of the flood protection system, professionals must pay attention to the preparation of the population, the provision of knowledge and information, which is an important element of the complex protection of the civilian population. The risk of floods has also increased in Serbia due to climate changes. Bearing in mind that major floods on the territory of Vojvodina occur every 10 years, one of the most effective methods of preparation for flood defense or evacuation of the population is the height representation of the terrain in a digital form and simulation of critical scenarios. Within the practical part of the work, a DEM (digital elevation model) of the part of the cadastral municipality of Bečej was created. In this area, there are residential buildings, country homes, ancillary facilities and economic facilities. According to the plan of the general regulation of Bečej, this territory is called a camp settlement and is the most critical area during the increase of the water level of the Tisa, because it is located between the embankment and

1. UVOD

U današnje vreme, u vezi sa nepoželjnim pojavama voda, neophodno je baviti se i pitanjima upravljanja vodama koja, između ostalog, uključuju kontrolu poplava, regulaciju reka, održavanje korita, unutrašnju odvodnju, osiguranje priobalja, itd. Kako bi se zaštitili građani države, postaje sve važnije ulagati u rešavanje situacije poplava i unutrašnjih voda na ugroženim područjima. Međutim, izgradnja i podizanje poplavnih nasipa samo je jedan od mogućih odgovora. Sa razvojem tehnologije, nova rešenja koja su brza i podržavaju efikasnu zaštitu, mogu se predstaviti donosiocima odluka, što bi značajno unapredilo postupke za sprečavanje vanrednih situacija. Pored tehničkog i tehnološkog razvoja sistema zaštite od poplava, profesionalci moraju obratiti pažnju na pripremu stanovništva, pružanje znanja i informacija, što je važan element složene zaštite civilnog stanovništva. Rizik od poplava je i usled klimatskih promena povećan i u Srbiji. Imajući u vidu da se veće poplave na teritoriji Vojvodine dešavaju na svakiih 10 godina, jedna od najefektivnijih metoda pripreme za odbranu od poplava ili evakuaciju stanovništva je visinska predstava terena u digitalnom obliku i simuliranje kritičnih scenarija.

U okviru praktičnog dela rada kreiran je DMV (digitalni model visine) dela katastarske opštine Bečej. Na tom području nalaze se stambene zgrade, kuće za odmor, pomoćni objekti i ekonomksi objekti. Po planu generalne regulacije Bečeja, ova teritorija se zove kamp naselje i najkritičnija je površina tokom povećavanja vodostaja Tise, jer se nalazi ispred nasipa prema reci. S obzirom na plan generalne regulacije i namenu površina, državni organi ne izdaju građevinske dozvole za ovakva područja.

the river. Considering the general regulation plan and the purpose of the areas, the state authorities do not issue building permits for such areas.

2. THEORETICAL BASICS

2.1 Methodology

At hydrological stations, water levels are monitored and measured using a water meter bar, limnigraph and/or digitally. Water level values are expressed in cm. The water meter is used to measure the height of water and its changes in space and time. The relative water level is the height of the water level in relation to the point "0" of the water meter. The unit of the relative height of water is cm, labeled as *H* and has a given value. The absolute height can be calculated from the relative water level, because each water meter bar has a given "0" elevation.

In order to analyze the data efficiently, having in mind that DTM consists of a large amount of data, a special organization and data structure is required [1]. Therefore, it is necessary to know the position and height of the points that are used to shape these models.

The DEM is a regular grid in which each cell (pixel) carries a record of the altitude of the terrain. The resolution of the model is determined by a cell size, which is expressed in m or km. The cell represents a certain area (eg 100x100 m) with a numerical value determined on the base of its center altitude [2].

A grid (regular grid) or raster is the simplest way to represent the surface of a terrain. Representation of the terrain in the form of a grid implies that the surface of the terrain is represented by a set of points with known heights arranged in a regular network of points. When representing the surface of the terrain through the raster, a method similar to digital raster images is used, where the surface is represented with

2. TEORIJSKE OSNOVE

2.1 Metodologija

Na hidrološkim stanicama, vodostaji se osmatraju i mere pomoću vodomerne letve, limnigrafa i/ili digitalno. Vrednosti vodostaja su izražene u cm. Vodomer služi za merenje visine vode i njene promene u prostoru i vremenu. Relativni nivo vode je visina nivoa vode u odnosu na tačku "0" vodomera. Jedinica relativne visine vode je cm, označena sa *H* i ima zadatu vrednost. Apsolutna visina može se izračunati iz relativnog nivoa vode, jer svaka vodomerna letva ima zadatu "0" kotu.

Da bi se analize mogle efikasno obaviti, s obzirom na to da se DMT sastoji od velike količine podataka, potrebna je posebna organizacija i struktura podataka [1]. Zbog toga je potrebno znati položaj i visinu tačaka koje se koriste za oblikovanje ovih modela.

Digitalni elevacioni model (DEM) predstavlja pravilnu mrežu u kojoj svaka ćelija (piksel) nosi zapis o nadmorskoj visini terena. Rezoluciju modela određuje veličina ćelije koja se izražava u m ili km. Ćelija predstavlja određeno područje (npr. 100x100 m) čija se numerička vrednost određuje na osnovu nadmorske visine njenog središta [2].

Grid (pravilna mreža) ili raster je najjednostavniji način za predstavljanje površi terena. Prikazivanje terena u formi grida podrazumeva da se površ terena predstavlja preko skupa tačaka sa poznatim visinama uređenim u pravilnu mrežu tačaka. Kod predstavljanja površi terena preko rastera, koristi se princip sličan kao kod digitalnih rasterskih slika gde se površ predstavlja preko kvadratnih elementa-piksela. Svakom pikselu rastera se square elements-pixels. Each raster pixel is assigned an appropriate value. 2D computer graphics is a representation of a digital image in two dimensions (height and width), that is, each pixel position is defined with two sizes (x, y).

Raster images, as mentioned, are composed of squares called pixels. Each pixel is characterized by color saturation (one or more of them, depending on whether they are monochrome or color images). The pixel tag is px. Resolution is the number of pixels that can be displayed in two dimensions, which simply expresses how many points the image consists of in the horizontal and vertical planes of the screen.

Photogrammetry is based on photography, as a carrier of information, and the recording of the Earth's surface is done from airplanes, drones, satellites or for the Earth. With the application of modern methods of digital photogrammetry, new possibilities of application appear by introducing faster, cheaper and more complex procedures, based on digital technology. Photogrammetry is one of the disciplines of geodesy which, using photographic images and the procedure of their measurement, defines the shape, size and position of objects and details registered at the time of shooting. One of the products of photogrammetry is a digital orthophoto plan, which shows the complete topography of the captured area in orthogonal projection. Field photography provides a lot of information and is more understandable than classic vector maps. Digital orthophoto is a geometrically corrected photograph in digital notation, created as a result of computer translation of digital images into orthogonal projection [3] [4].

dodeljuje odgovarajuća vrednost. 2D računarska grafika je prikaz neke digitalne slike u dve dimenzije (visine i širine), odnosno, svaka pozicija piksela definisana je sa dve veličine (x, y).

Rasterske slike, kao što je rečeno, sastavljene su od kvadratića koji se nazivaju pikseli. Svaki piksel karakteriše zasićenost bojom (jednom ili više njih, u zavisnosti od toga da li je reč o monohromatskim ili slikama u boji). Oznaka za piksel je px. Rezolucija je broj piksela koji se mogu prikazati u dve dimenzije, čime se jednostavno iskazuje od koliko tačaka se slika sastoji u horizontalnoj i vertikalnoj ravni ekrana.

Fotogrametrija se bazira na fotografiji, kao nosiocu informacija, te se snimanje Zemljine površine vrši iz aviona, bespilotnih letelica, satelita ili za Zemlje. Primenom savremenih metoda digitalne fotogrametrije javljaju se nove mogućnosti primene uvođenjem bržih, jeftinijih i kompleksnijih postupaka, utemeljenih na digitalnoj tehnici. Fotogrametrija je jedna od disciplina geodezije koja, služeći se fotografskim snimcima i postupkom njihovog merenja, definiše oblik, veličinu i položaj objekata i detalja registrovanih u momentu snimanja. Jedan od proizvoda fotogrametrije je digitalni ortofoto plan, koja prikazuje kompletnu topografiju snimljenog područja u ortogonalnoj projekciji. Terenska fotografija pruža mnogo informacija i razumljivija je od klasičnih vektorskih karata. Digitalni ortofoto je geometrijski ispravljena fotografija u digitalnom zapisu, nastala kao rezultat kompjuterskog prevođenja digitalnih slika na ortogonalnu projekciju [3] [4].

2.2 Research area and objectives

The city of Bečej is a city settlement and the seat of the municipality of the same name, which is located in the South Bačka District, in the Autonomous Province of Vojvodina. According to the 2011 census, the city of Bečej had 23.985 inhabitants. The surface is irregular in shape and elongated in the northwest-southeast direction. It is 20 km long and about 12 km wide. The area of the cadastral municipality is 227 km^2 and borders the cadastral municipalities of Bačko Petrovo Selo, Novi Bečej, Bačko Gradište, Radičević, Srbobran, Mileševo. Between Bečej and Novi Bečej is the international river Tisa, the largest tributary of the Danube, which flows through the territory of four countries. Its total length is 966 km, of which 164 km through Serbia. Within the practical part of the work, a digital elevation model (DEM) was created for a part of the cadastral municipality of Bečej. 15 ha were recorded, of which 54.248 m^2 were analyzed. In that territory, there are residential buildings, holiday homes, auxiliary facilities and economic facilities. The aim of this paper is to show the terrain, spill analysis and damage analysis in the weekend settlement in Bečej on the right bank of the river Tisa.

2.2 Područje i ciljevi istraživanja

Grad Bečej je gradsko naselje i sedište istoimene opštine koja se nalazi u Južnobačkom okrugu, u Autonomnoj Pokrajini Vojvodini. Prema popisu iz 2011. grad Bečej je imao 23.985 stanovnika. Površina je nepravilnog oblika, a izdužen je pravcem severozapad-jugoistok. Dugačak je 20 km, a širok oko 12 km. Površina katastarske opštine je 227 km^2 i graniči se sa katastarskim opštinama Bačko Petrovo Selo, Novi Bečej, Bačko Gradište, Radičević, Srbobran, Mileševo. Između Bečeja i Novog Bečeja je međunarodna reka Tisa, najveća pritoka Dunava, koja protiče kroz teritoriju četiri države. Njena ukupna dužina iznosi 966 km, a od toga kroz Srbiju 164 km. U okviru praktičnog dela rada kreiran je digitalni model visine (DMV) za deo katastarske opštine Bečej. Snimljeno je 15 ha, a od toga analizirano 54 248 m2. Na toj teritoriji se nalaze stambene zgrade, kuće za odmor, pomoćni objekti i ekonomski objekti. Cilj rada je prikazivanje terena, analiza izlivanja i analiza štete u vikend naselju u Bečeju na desnoj obali reke Tise.

3. THEORETICAL BASICS

3.1 Preparation works

Preparatory work was done before the start of data collection. In this case, there is no need to create a plan of landmark layout because it uses unmanned aerial vehicles with integrated RTK GNSS module of geodetic accuracy (1 cm + 1 ppm). In order to ensure quality control of the obtained models, control points have been set up in the territory of interest. The most effective signaling of control points is with white paint on concrete or

3. REZULTATI I DISKUSIJA

3.1 Pripremni radovi

Pripremni radovi su odrađeni pre početka prikupljanja podataka. U ovom slučaju, nema potrebe za izradom plana rasporeda orijentacionih tačaka jer se koristi bespilotna letelice sa integrisanim RTK GNSS modulom geodetske tačnosti (1 cm + 1 ppm). U cilju obezbeđenja kontrole kvaliteta dobijenih modela, postavljene su kontrolne tačke na teritoriji od interesa. Najefikasnije signalisanje kontrolnih tačaka je sa belom bojom na betonu ili dirt, to be as visible as possible. The used control points were measured in advance with a GNSS device of geodetic accuracy, in RTK mode, using 3 measurements of 30 s each. The coordinates for the four points are determined by the GNSS device, and one point is within the city polygon network P8607, which is not newly established, it is only marked and its position is controlled. The coordinates of the control points used are given in Table 1.

zemlji, da bude što očiglednije. Korišćene kontrolne tačke su unapred izmerene GNSS uređajem geodetske tačnosti, u RTK režimu rada, tehnikom sa 3 merenja po 30 s. Koordinate za četiri tačke su određene GNSS uređajem, a jedna tačka je unutar gradske poligonske mreže P8607 koja nije novouspostavljena, samo je obeležena i izvršena je kontrola njenog položaja. Koordinate korišćenih kontrolnih tačaka su navedene u Tabeli 1.

Tabela 1- Koordinate kontrolnih tačaka
Table 1 - Koordinates of control points

Naziv	*Y* [m]	*X* [m]	*H* [m]
1	7426806,238	5052118,570	79,276
2	7426965,885	5052200,245	77,915
3	7427111,119	5052253,833	77,318
4	7427307,679	5052274,280	77,016
P8607	7426836,840	5052225,880	81,090

3.2 Calculation of parameters for data collection

Equations were used to determine the approximate accuracy estimate for the ideal case of stereorestitution. The precondition is that the error per axis should not be greater than 4 cm. When calculating the predicted flight altitude *h* = 100 m, the longitudinal fold, θ_{pod}= 70% and the transverse fold θ_{pop} = 80% were chosen. The camera parameters are taken from the official specification of the drone. Axis accuracy: $\sigma_X = 2{,}27$ cm, $\sigma_Y = 3{,}83$ cm, $\sigma_z = 2{,}92$ cm.

3.3 Data collection and processing

Data was collected by the DJI Phatom 4 RTK drone from a height of 100 m. Date and time of flight is 04.06.2021. at 15:30. The flight plan is set in the field using the original DJI controller on which the Google Maps application is installed. The recorded area is 15 ha, and the flight duration was 12,5 min. 271 photos were taken. RTK mode

3.2 Proračun parametara za prikupljanje podataka

Korišćene su formule za određivanje približne ocene tačnosti za idealan slučaj stereorestitucije. Preduslov je da greška po osama ne bude veća od 4 cm. Prilikom računanja predviđena visina leta *h* = 100 m, izabran je podužni preklop θ_{pod} = 70% i poprečni preklop θ_{pop} = 70%. Parametri kamere su preuzeti iz zvanične specifikacije bespilotne letelice. Tačnost po osama: $\sigma_X = 2{,}27$ cm, $\sigma_y = 3{,}83$ cm, $\sigma_z = 2{,}92$ cm

3.3 Prikupljanje i obrada podataka

Podaci su prikupljeni bespilotnom letelicom DJI Phatom 4 RTK sa visine od 100 m. Datum i vreme letenja je 04.06.2021. u 15:30. Plan leta je zadat na terenu pomoću originalnog DJI kontrolera na koji je instalirana aplikacija Google Maps. Snimljena površina je 15 ha, a trajanje leta je bilo 12,5 min. Napravljena je 271 fotografija. Prilikom letenja korišćen je was used during the flight, and corrections were taken from the permanent CORS network Vekom VRS. During the flight, 22-28 satellites were used, as many as were in the field of view of the GNSS receiver on the aircraft. The first step of digitization obtained image into a state coordinate system. At the end of each shooting era, a so-called "Rinex Timestamp" text file is generated in the spacecraft, which contains data on the coordinates of the camera's projection center for each photograph. The coordinates obtained during the recording need to be transformed into a coordinate system of the state. This paper uses GRIDER 3.1, the official coordinate transformation program, developed by the Republic Geodetic Authority. The next step uses the pix4D mapper program to process, orient the images, aerotriangulate, and generate the final recording results. After processing in the Pix4D program, an orthophoto and a digital surface model (DSM) were obtained. After creating DSM and orthophoto files, a comparison of the obtained digital model and the used control points was performed. The quality of digitization was tested by analyzing the differences between digitized and conditionally correct coordinates of control points. The calculated differences are shown in Table 2.

RTK mod, a korekcije su preuzimane sa permanentne CORS mreže Vekom VRS. Tokom letenja bilo korišćeno 22-28 satelita, koliko je bilo u vidnom polju GNSS prijemnika na letelici. Prvi korak digitalizacije je da se koordinate dobijene slike transformišu u državni koordinatni sistem. Prilikom završetka svake epohe snimanja, u letelici se generiše takozvani „Rinex Timestamp" tekstualni fajl koji sadrži podatke o koordinatama projekcionog centra kamere za svaku fotografiju. Dobijene koordinate tokom snimanja potrebno je transformisati u državni koordinatni sistem. U ovom radu je korišćen GRIDER 3.1, zvaničan program za transformaciju koordinata, napravljen od strane Republičkog geodetskog zavoda. U sledećem koraku koristi se program pix4D mapper za procesiranje, orijentaciju snimaka, aerotriangulaciju i generisanje krajnjih rezultata snimanja. Nakon obrade u Pix4D programu, dobija se ortofoto i digitalni model površi (Digital Surface Model - DSM). Nakon kreiranja DSM i ortofoto faljova, izvršeno je upoređivanje dobijenog digitalnog modela i korišćenih kontrolnih tačaka. Kvalitet izvršene digitalizacije testiran je analizom razlika digitalizovanih i uslovno tačnih koordinata kontrolnih tačaka. Izračunate razlike prikazuje Tabela 2.

Tabela 2 - Razlika uslovno tačnih i digitalizovanih koordinata
Table 2 – Difference of conditionally correct and digitized coordinates

Naziv	ΔY [m]	ΔX [m]	Δh [m]
1	0,031	0,040	-0,037
2	-0,037	0,029	-0,041
3	-0,030	0,034	-0,037
4	-0,031	0,043	0,011
P8607	-0,034	-0,029	-0,032

Checking the quality of the performed recording and digitization was done by comparing the expected values of the differences digitized to the conditionally correct coordinates. The null and alternative hypothesis is set, as well as

Provera kvaliteta izvršenog snimanja i digitalizacije urađeno je pomoću testiranja očekivanih vrednosti razlika digitalizovanih od uslovno tačnih koordinata. Postavljaju se nulta i alternativna hipoteza, kao i test

test statistics for differences on all three coordinate axes, according to Table 1 [5]:

statistika za razlike po sve tri koordinatne ose, prema Tabeli 1 [5]:

$$H_0: \overline{\Delta Y}=0 \qquad H_A: \overline{\Delta Y} \neq 0 \qquad (1)$$

$$T_1: \frac{\overline{\Delta Y}-0}{\frac{\sigma_Y}{\sqrt{n}}} < t_{0,95}(f) \qquad (2)$$

$$T_1: 0,14 < 2,78$$

$$H_0: \overline{\Delta X}=0 \qquad H_A: \overline{\Delta X} \neq 0 \qquad (3)$$

$$T_2: \frac{\overline{\Delta X}-0}{\frac{\sigma_X}{\sqrt{n}}} < t_{0,95}(f) \qquad (4)$$

$$T_2: 0,16 < 2,78$$

$$H_0: \overline{\Delta H}=0 \qquad H_A: \overline{\Delta H} \neq 0 \qquad (5)$$

$$T_3: \frac{\overline{\Delta H}-0}{\frac{\sigma_H}{\sqrt{n}}} < t_{0,95}(f) \qquad (6)$$

$$T_3: 0,25 < 2,78$$

As all three test statistics, T_1, T_2 and T_3 are less than the corresponding quantile of the Student's t distribution, we conclude that in all three cases the null hypothesis is adopted, that is, that the differences in coordinates are within the required accuracy.

3.4 Analyzes and simulations on the territory of the camp settlement in Bečej

The town of Bečej is located on the right shore of the Tisa river, protected by an embankment intended for protection from 100 years old high waters. In the analyzed area of 54.248 m^2 and located in front of the embankment, there are about 150 buildings that would be damaged during a flood. As it was stated, the Camp settlement is in a dangerous zone during floods, and that is why it is necessary to develop a methodology that would predict possible high waters. The whole area is at an altitude of 76,90 to 78,70 m.

The task is to determine how large area of the Camp settlement would be under water if there were large spills of the

Kako su sve tri test statistike, T_1, T_2 i T_3 manje od odgovarajućeg kvantila Studentove t raspodele, zaključujemo da se u sva tri slučaja usvaja nulta hipoteza, odnosno, da su razlike koordinata u granicama tražene tačnosti.

3.4 Analize i simulacije na teritoriji kamp naselja u Bečeju

Grad Bečej se nalazi na desnoj obali Tise, zaštićen je nasipom predviđenim za zaštitu od 100-godišnjih velikih voda. Na analiziranom području koje je površine 54248 m^2 i nalazi se ispred nasipa, ima oko 150 objekata koji bi bili oštećeni prilikom izlivanja. Kao što je rečeno, Kamp naselje je u opasnom pojasu prilikom poplava i zato je potrebno razviti metodologiju kojom bi se izvršila predikcija eventualnih visokih voda. Celo područje je na nadmorskoj visini od 76,90 do 78,70 m.

Zadatak je utvrditi kolika bi površina Kamp naselja bila pod vodom ukoliko bi došlo do velikih izlivanja Tise uporedivih sa poznatim, kada su zabeleženi dostignuti nivoi reke.

Tisa, comparable to the known one, when the reached river levels were recorded.

Official data on the level of the Tisa were obtained from the representatives of JVP Vode Vojvodine from Novi Bečej. In the immediate vicinity of the location where the experiment was conducted, at about 10 km, there is a measuring station of the Republic Hydrometeorological Institute of Serbia (RHMZ). Data for all recorded dates of major floods, of the measuring station in question was downloaded from the RHMZ website.

As a next step, a flood simulation was performed with the Global Mapper software package.

Zvanični podaci o nivou Tise dobijeni su od zastupnika JVP Vode Vojvodine iz Novog Bečeja. U neposrednoj blizini lokacije na kojoj se sproveden eksperiment, na oko 10 km, postoji merna stanica Republičkog hidrometeorološkog zavoda Ssrbije (RHMZ). Sa sajta RHMZ preuzeti su podaci za predmetnu mernu stanicu za sve zabeležene datume kada su zabeležene velike poplave.

U sledećem koraku je izvršena simulacija poplava u softverskom paketu Global Mapper.

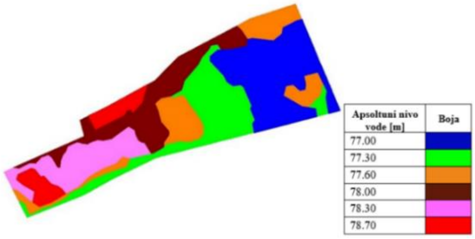
Слика 1 – Анализирана површина - Обухват

Figure 1 – Analyzed area – Coverage

The boundary of the analyzed area is marked in black and shown on Figure 1. To check the simulation, it is necessary to know the water level of the river at the time of recording by the drone. The level of the Tisa for the day of filming was taken from the RHMZ website (06/04/2021). The absolute height of the river was 75,37 m, which is in accordance with the model obtained by applying UAV photogrammetry. In the simulation, the water level is continuously increased at constant steps of value. When the water in the Global Mapper increases, it is necessary to monitor the growth of the area under flood. The "area feature" option is used, which is used to draw a polygon for each given height. Each

Granica analiziranog područja je označena crnom bojom i prikazana na Slici 1. Za kontrolu simulacije, potrebno je znati vodostaj reke u trenutku snimanja bespilotnom letelicom. Sa internet sajta RHMZ preuzet je nivo Tise za dan snimanja (04.06.2021.). Apsolutna visina reke je bila 75,37 m, što je saglasno sa modelom dobijenim primenom UAV fotogrametrije. U simulaciji, kontinuirano se povećava nivo vode za određenu konstantnu veličinu. Prilikom povećanja vode u Global Mapper-u potrebno je pratiti i rast površine pod poplavom. Koristi se opcija „area feature“, pomoću kojeg se nacrta poligon za svaku zadatu visinu. Svaka apsolutna visina Tise preko 76,90 m pokriva deo površine od vikend absolute height of the Tisa over 76,90 m covers a part of the area of the weekend settlement. In the simulation, steps of 30 - 40 cm were used to gradually increase the height, as shown on Figure 2, where each phase is marked with a different color.

naselja. U simulaciji za postepeno povećanje visine su korišćeni koraci 30 – 40 cm, što prikazuje Slika 2, gde je svaka faza označena drugom bojom.



Slika 2 - Prikazane površine na različitim visinama
Figure 2 - Shown areas at different heights

Figure 3 shows the situation when the level of the Tisa is at an absolute height of 77,00 m. In this case, the underwater area is 14.374 m^2.

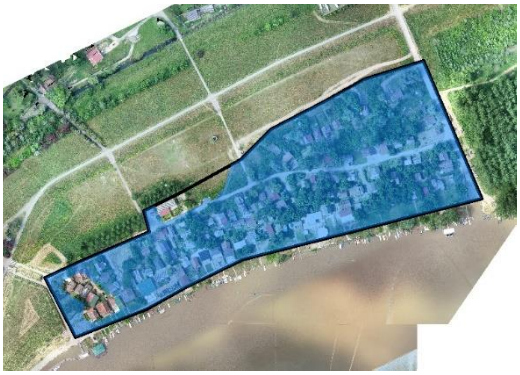
Na slici 3 je prikazana situacija kada je nivo Tise na apsolutnoj visini 77,00 m. U ovom slučaju, površina pod vodom je 14.374 m^2.

Slika 3 - Poplavna površina za apsolutnu visinu Tise na 77,00 m
Figure 3 - Flood area for the absolute height of the Tisa at 77,00 m

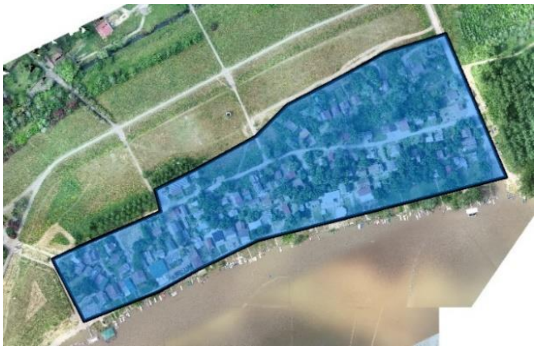
Figure 4 shows the situation in the case when the level of the Tisa is at an absolute height of 77,30 m, and the flood area is 25.601 m^2.

Na slici 4 je prikazana situacija u slučaju kada je nivo Tise na apsolutnoj visini 77,30 m, a poplavna površina 25.601 m^2.

Slika 4 - Poplavna površina za apsolutnu visinu Tise na 77,30 m
Figure 4 - Flood area for the absolute height of the Tisa at 77,30 m



Slika 5 - Poplavna površina za apsolutnu visinu Tise na 78,30 m
Figure 5 - Flood area for the absolute height of the Tisa at 78,30 m



Slika 6 - Poplavna površina za apsolutnu visinu Tise na 78,70 m
Figure 6 - Flood area for the absolute height of the Tisa at 78,70 m

The water levels are shown in figures 3, 4, 5 and 6. When the height of the Tisa is over 78,70 m, the whole area is under water.
Table 3 lists the floodplains calculated as a percentage by height.

Nivoi vodostaja su prikazani na slikama 3, 4, 5 i 6. Prilikom visine Tise preko 78,70 m, celo područje je pod vodom.
U Tabeli 3. su navedene poplavne površine izračunate procentualno po visinama.

Tabela 3 - Prikazane poplavne površine
Table 3 – Floodareas shown

Redni broj	Aps. nivo vode	Poplavna površina	
	[m]	[m²]	[%]
1	77,00	14 374	26,50
2	77,30	25 601	47,19
3	77,60	34 035	62,74
4	78,00	43 422	80,04
5	78,30	50 550	93,18
6	78,70	54 248	100

For the simulation of large floods, official data on the heights of the Tisa were used by the representatives of JVP Vode Vojvodine. The oldest data on the great floods in Novi Bečej is from 1879, when the highest relative height was 628 cm (absolute height 78.15 m) (Figure 7).

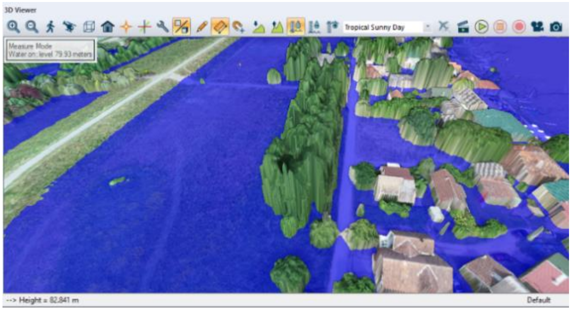
Za simulaciju velikih poplava korišćeni su zvanični podaci o visinama Tise od strane zastupnika JVP Vode Vojvodine. Najstariji podatak o velikim poplavama u Novom Bečeju je iz 1879. godine, kada je najveća relativna visina bila 628 cm, tj. apsolutna visina 78,15 m (Slika 7).

Slika 7 - Velika voda iz 1879. godine sa apsolutnom visinom od 78,15 m
Figure 7 - Great water from 1879 with an absolute height of 78,15 m

Since the water level of the Tisa near Novi Bečej has been recorded, the highest was on April 21, 2006. year, when it had a relative height of 806 cm (absolute height was 79.93 m). The comparison shows that out of the total area of 54 248 m^2, 46,644 m^2 were under water. The water level was also dangerous for the town of Bečej, because the lowest height of the

Od kad se beleži vodostaj Tise kod Novog Bečeja, najveća visina je bila 21.04.2006. godine, kad je imala relativnu visinu 806 cm (apsolutna visina je bila 79,93 m). Prilikom upoređivanja, vidi se da je od ukupne površine 54 248 m2, pod vodom bilo 46 644 m2. Vodostaj je bio opasan i za grad Bečej, jer je najniža visina nasipa na 81,00 m, a visina vode između 1,10 embankment is 81.00 m, and the water height is between 1.10 m and 3.20 m from the terrain (Figure 8).

m i 3,20 m od terena (Slika 8).



Slika 8 - Prikaz nivo vode na visini od 79,93 m
Figure 8 - Display of water level at a height of 79.93 m

Table 4 lists data on high waters in the last 142 years.

Tabela 4. navodi podatke o velikim vodama u poslednje 142 godine.

Tabela 4 - Velike vode u poslednje 142 godine [6]
Table 4 - High waters in the last 142 years [6]

Godina velike vode	Aps. nivo vode	Poplavna površina	
	[m]	[m^2]	[%]
1879.	78,15	46 644	85,98
1895.	79,19	54 248	100,00
1919.	79,21	54 248	100,00
1940.	79,43	54 248	100,00
1970.	79,72	54 248	100,00
1981.	79,16	54 248	100,00
2006.	79,93	54 248	100,00

4. CONCLUSION

The rapid evolution of unmanned aerial vehicles has led to a large expansion of their use for photogrammetry and spatial data collection. Having in mind the growing need and importance of digital modeling and terrain representation, this work presents the methodology of creating a digital altitude model using the results of photography by the photogrammetric method, using unmanned aerial vehicles.

In the experimental part, an UAV with an integrated GNSS RTK module was

4. ZAKLJUČAK

Pojava bespilotnih letelica dovela je do velike ekspanzije njihove upotrebe za potrebe fotogrametrije i prikupljanja prostornih podataka. Imajući u vidu sve veću potrebu i značaj digitalnog modeliranja i predstave terena u ovom radu je prikazana metodologija kreiranja digitalnog modela visina koristeći rezultate snimanja fotogrametrijskom metodom, upotrebom bespilotnih letelica.

U eksperimentalnom delu rada korišćena je bespilotna letelica sa integrisanim GNSS RTK modulom koji used, which determines the coordinates of the projection center of images with an accuracy of 2-3 cm. Such devices eliminate the need to set a large number of landmarks, which makes field work significantly more economical and efficient. The quality analysis of the obtained digital altitude model was performed using 5 control points whose coordinates were previously obtained by classical imaging methods. Test statistics show that the deviations at the control points are within the permitted measurement accuracy.

The site where the experiment was conducted covers the territory of the Camp Settlement near the city of Bečej in an area of 54248 m^2. The camp settlement is spread out at altitudes from 76.50 m to 78.70 m.

The analysis of data on water levels of the Tisa river, which were taken from the measuring station of the Hydro-meteorological Institute, in the immediate vicinity of the Camp settlement, was performed. Based on the collected data, on the day of recording by the unmanned aircraft, the height of the water mirror was synchronized in order to harmonize the system of heights of the obtained altitude model and the data obtained from RHMZ. A flood simulation was performed by gradually raising the Tisa river's water level by 30 cm and 40 cm. The simulation determined that the level of the Tisa, in case it exceeds the absolute elevation of 76.90 m, can be risky for buildings and people. Additionally, a simulation of the water level was performed for some characteristic dates in the past when high water levels and floods were recorded. The percentage of endangered area of the chosen location in case of high waters and flooding by the river was also presented.

This paper outlined how modern technologies such as unmanned aerial vehicles can be used for altitude modeling and flood prediction. The presented methodology is efficient and

obezbeđuje određivanja koordinata projekcionih centara snimaka sa tačnošću 2-3 cm. Ovakvi uređaji isključuju potrebu za postavljanjem velikog broja orijentacionih tačaka što terenske radove čini značajno ekonomičnijim i efikasnijim. Izvršena je analiza kvaliteta dobijenog digitalnog visinskog modela upotrebom 5 kontrolnih tačaka čije su koordinate prethodno dobijene klasičnim metodama snimanja. Test statiskikom je pokazano da su odstupanja na kontrolnim tačkama u okvirima dozvoljene tačnosti merenja.

Lokalitet na kome je sproveden eksperiment obuhvata teritoriju Kamp naselja u blizini Bečeja u površini od 54 248 m^2. Kamp naselje se prostire na nadmorskim visinama od 76,50 m do 78,70 m.

Izvršena je analiza podataka o vodostajima na reci Tisi, koji su preuzeti sa merne stanice Hidrometeoroškog Zavoda, neposrednoj blizini Kamp naselja. Na osnovu podataka o vodostaju, na dan snimanja bespilotnom letelicom, izvršena je sinhronizacija visine vodenog ogledala radi usaglašavanja sistema visina dobijenog visinskog modela i podataka dobijenih iz RHMZ. Izvršena je simulacija poplava postepenim podizanjem nivoa Tise za vrednosti od 30 cm i 40 cm. Simulacijom je utvrđeno da nivo Tise koji prelazi apsolutnu kotu od 76,90 m, može biti rizičan za objekte i ljude. Dodatno je izvršena i simulacija nivoa Tise za neke karakteristične datume u prošlosti kada su zabeleženi visoki nivoi Tise i poplave. Prikazano je koliki bi procenat predmetne lokacije bio ugrožen kada bi se ponovili isti novio vode i izlivanja reke Tise.

Ovaj rad je prikazao na koji način se mogu koristiti savremene tehnologije poput bespilotnih letelica za potrebe visinskog modeliranja terena i predikcije poplava. Predstavljena metodologija je efikasna i daje rezultate koji su pogodni za precizne simulacija potencijalnih poplava. Ovakav pristup može gives results that are suitable for accurate simulations of potential floods. This approach can be a good prevention measure to protect people and facilities in vulnerable areas.

predstavljati dobru meru prevencije u cilju zaštite ljudi i objekata u ugroženim područjima.

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