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FLUVIAL DEPOSITION IN GROYNE FIELDS OF THE MIDDLE COURSE OF THE DANUBE RIVER

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Original scientific paper
The study analyses fluvial deposition (sedimentation) in groyne fields constructed on the meandering section of the Danube River from Novi Sad (Republic of Serbia) to the border of the Republic of Croatia, the Republic of Serbia and Hungary (1255 ÷ 1433 km stations). By processing satellite images (Google Earth) of the studied area, groyne systems were detected at 25 locations and their characteristics and sedimentation by the river deposited materials were elaborated on more than 100 groyne fields. Results show that on the observed groyne fields and systems, the new areas, formed by fluvial deposition, are overspread on totally over 5,5 million m^2 (cca 3,13 million m^2 on the left and 2,38 million m^2 on the right riverside). Distribution of groyne fields more affected by fluvial sediments was substantially greater on the left (~60 %) than on the right (~40 %) Danube riverside. On predominant portion of the groyne systems (15/25) fluvial sedimentation occupied 40 ÷ 80 % of the total groyne field area.

Keywords: *Danube R., deposition, groyne (groin) fields, sedimentation*

Zasipanje međunaperskih polja (prostora između regulacijskih pera) na srednjem toku Dunava

Izvorni znanstveni članak
Rad se bavi analizom riječne depozicije (zasipanja) u međunaperskim poljima (prostoru između regulacijskih pera) izgrađenim na meandrirajućoj sekciji Dunava od Novog Sada (Republika Srbija) prema granici Republike Hrvatske, Republike Srbije i Mađarske (stacionaža km 1255 ÷ 1433). Obradom satelitskih snimaka (Google Earth) istraživanog područja, utvrđeni su sustavi napera na 25 lokacija te su elaborirane njihove značajke i zasipanje riječnim nanosom na preko 100 naperskih polja. Rezultati pokazuju da se na promatranim naperskim poljima i sustavima nove površine, nastale riječnom depozicijom, rasprotiru na preko 5,5 milijuna m^2 (oko 3,13 milijuna m^2 na lijevoj i 2,38 milijuna m^2 na desnoj obali). Distribucija naperskih polja pod većim utjecajem riječne depozicije je bila znatno veća na lijevoj (~60 %) nego na desnoj (~40 %) obali Dunava. Na predominantnom dijelu naperskih sustava (15/25) riječna depozicija je zauzela 40 ÷ 80 % ukupne površine međunaperskih polja.

Ključne riječi: *Dunav, nanos, regulacijska pera (naperi), zasipanje*

1 Introduction

River groynes (groins) represent massive regulation hydrotehnical structures, built in the river base from autochthonous or alochthonous materials (e.g. shore, concrete, rock, gravel, sand, wood), and positioned across the main water flow. They are overspreading in the form of trapezoid dikes, from the riverbank (as a groyne root) to the projected regulation line (as a groyne head) of the water course. The main purposes of the river groyne are: i) fixation (stabilisation) of projected regulation river line, ii) constriction of river bed for more concentrated (directed) and increased river (water/ice) flows, iii) control and prevention of riverbank (lateral) erosion (e.g. due to watercourse meandering), iv) formation of new riverside as a consequence of groyne fields (described below), v) navigation improvement, etc. Groynes are mostly built sequentially on convective riversides, as systemic and grouped hydro-contractures, i.e. groyne systems (Fig. 1). Within a particular groyne system, the area between of two groynes forms a so called groyne field, which is over the time exposed to sedimentation of river deposited materials, and thus formation of new riverbanks (Fig. 1) [1, 2, 3, 4]. Obtained effects on groyne systems can be monitored and evaluated based on quantity and dynamics of fluvial deposited materials [5, 6, 7, 8].

Groynes are of crucial importance for meandering river courses and their floodplain areas, as well as marine ecosystems. Accordingly, a river base is generally very often formed on unconsolidated sediment of sand, gravel, loam, silt, and/or clay fractions, and thus very susceptible to its permanent morphological (terraces, contours) modifications. Transformations of the main river bed occur under different hidrological-hydraulical (e.g. amount and properties of river sediment material) and biological (e.g. abundance and type of vegetation) impacts [9, 10, 11, 12]. These modifications may induce unexpected negative environmental consequences at wider regional level, but also they can be prevented and managed by appropriate regulative hydrotechnical structures at river courses, such as groyne systems [13, 14, 15, 16].

Figure 1. Groynes on Danube R. (a - Google Earth, b - http://www.panoramio.com source)

Namely, newly created areas, formed as a consequence of fluvial sedimentation (deposition), besides their primary hydrotechnical function, are important also from ecological perspectives [17, 18], given that deposited (in)organic materials represent very suitable medium for (annual/perennial) vegetation development. Furthermore, this area may substantially contribute to biodiversity and represent permanent biotopes or periodical corridors for different animal species, whereas relatively shallow waters and presence of submersed vegetation ensure favourable conditions for fish spawning [19, 20, 21, 22, 23].

The Danube River is one of the most important European rivers which flows south-eastward for a distance of around 2780 km before it empties into the Black Sea. Across 19 countries (Albania, Austria, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Germany, Hungary, Italy, Moldova, Montenegro, Poland, Romania, Serbia, Slovakia, Slovenia, Switzerland, Macedonia and Ukraine) it creates the Danube River basin (>801 460 km^2) with >81 million inhabitants who greatly impact the natural environment of the basin, causing pressures on its water quality/quantity and biodiversity [24]. At the middle course of the Danube River (e.g. from Novi Sad to the border of Croatia, Serbia and Hungary), its course is substantially meandering and over the time, during high water-level periods, preferentially on concave and shallow riversides, lateral erosion represents a serious threat for banks disrupting. To control and prevent the river's hydraulic properties, in the past were constructed groyne systems, which markedly differ from other hydro-structures in view of their abundance and functionality on this section. Therefore, the main purpose of this study was to analyse fluvial sedimentation in groyne fields at this triangle international border of the middle course of the Danube River and their environmental impacts.

2 Material and methods

The study elaborates the section of the Danube R. from Novi Sad (Republic of Serbia) to the border of the Republic of Croatia, the Republic of Serbia and Hungary, in total length of almost 180 km (stations from km 1255 to km 1433). Water flows on this section of the Danube River vary from minimally 610 m^3/s (before discharging to the Drava River), namely 680 m^3/s (after discharging to the Drava River), to maximally 7700 ÷ 8600 m^3/s, i.e. on average 2400 ÷ 3000 m^3/s [25, 26]. Contours of the Danube river-bed on this course section are very susceptible to continuous modifications what is very common for alluvial lowland courses. Regarding the stabilisation of river-bed, different hydro-technical measures and operations were implemented in the past on the studied area (e.g. dykes, banks, parallel structures, groynes, compartments, rocky depositions etc). Generally, the most used material for construction of groyne bodies on observed area is stone fraction from 150 ÷ 450 mm, deposited onto the track ballast. Groyne wings are also very present in this section and are mostly built from the stone 200-400 mm fraction, and placed onto fascine mattresses. Groynes are grouped into systems to ensure maximally favourable hydraulic effects, i.e. intercepted riverside's erosion, reduced sediment deposition of the river materials, retarded formation of new riversides, etc.

According to recent data [26], the total length of groynes is around 28 km or approximately 12 % of the total length of all regulation hydrotehnical constructions built on this section of the Danube R. Particular lengths of groyne systems vary in the range of 19 ÷ 400 m (1/3 ÷ 1/10 of water course width), and in general depend on specific conditions. Crowns of groynes are projected on multiannual average course water-level (plus 0,5 ÷ 1,0 m) with gradually decreasing in direction of watercourse flow (e.g. from 84,00 m above sea l. of the most-upstream groyne to 75,04 m above sea l. of the most-downstream groyne).

Fluvial deposition and condition of groyne fields in a particular system were analysed by processing of satellite images of the studied area (taken during November and December 2006) in the computer software *Google Earth.* On the same date the satellite data images were taken, water levels on observed course section of the Danube R. were also recorded from several official measuring stations as follows: at Bezdan (192 cm or 82,56 m above sea l.), at Apatin (621 cm or 85,05 m above sea l.), at Bogojevo (613 cm or 83,59 m above sea l.), at Bačka Palanka (151 cm or 75,48 m above sea l.) and at Novi Sad (83 cm or 72,56 m above sea l.).

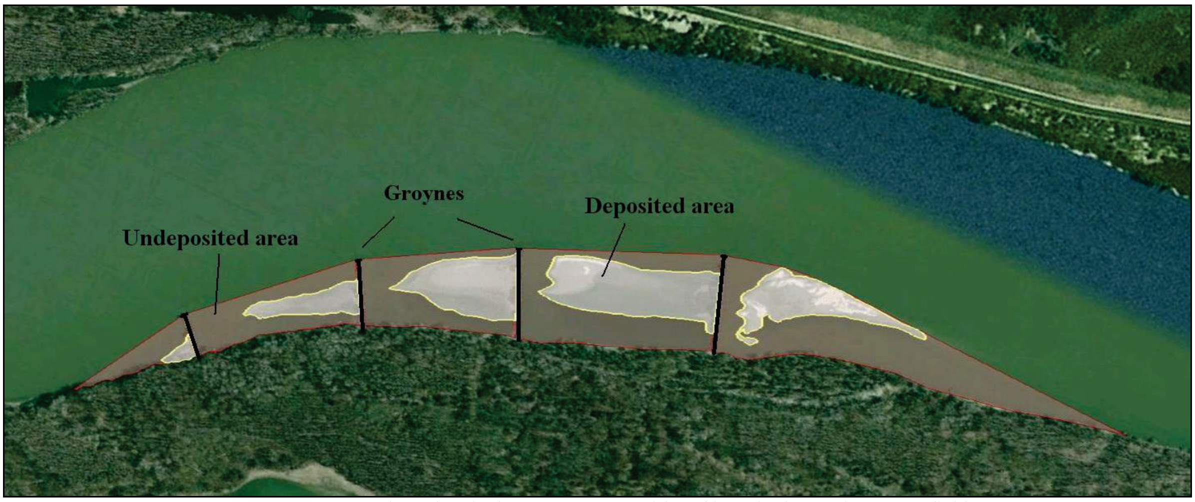

Figure 2 Presentation of typical groyne system with un/deposited areas in groyne field

All technical data related to observed groyne systems (positions, outlines) were taken from the Cadastre of hydrotechnical structures [27]. By means of available graphical tools incorporated into the *Google Earth* package, on particular groyne system were digitalised their elements to be calculated and compared maximally possible and currently present area under deposited (sediment) fluvial materials, i.e. undeposited area (Fig. 2). Separately were analysed the groyne systems constructed on the left and the right bank of the Danube R.

3 Results and discussion

On analysed satellite images of the middle course of the Danube riverside 25 groyne systems were detected in total (13 on the left and 12 on the right bank), including different hydrotechnical elements, as well as the area formed by fluvial deposit materials among them. Totally were observed and analysed 113 groyne fields along the studied riverside (57 on the left and 56 on the right) (Fig. 3). Deposition of fluvial sediment materials caused the formation of new areas different in shape and size. Filled areas varied markedly (from 0 up to 457 400 m^2 at stations km ~1423) and yielded in average around 55 000 m^2 per one groyne field, i.e. around 3 133 600 m^2 in total were the newly formed filled areas of groyne fields on the observed left Danube riverside. On the right bank, the size of filled area in groyne fields (from 0 up to 477 000 m^2 at stations km ~1270) was on average 42 500 m^2, and totally reached around 2 378 500 m^2 (Fig. 3).

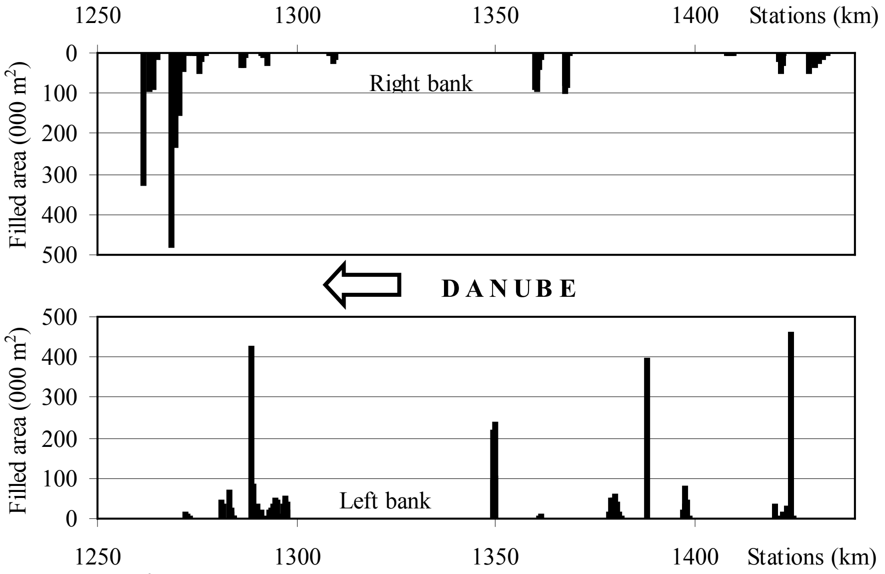

Figure 3 Total filled area (m^2) of groyne fields formed by fluvial deposition on the studied middle course of the Danube River

Also elaborated was the distribution of particular gryone field under fluvial sediments (i.e. covered with fluvial deposited material) in comparison to its total area. Accordingly, the percentage of groyne fields whose total area was >50 % covered with fluvial sediments was substantially higher on the left bank (in around 60 % of analysed groynes) compared to the right bank (in around 40 % of analysed groynes) of the Danube R. (Fig. 4). These observations are in accordance with similar earlier findings, and can be explained by the so called Von Baer (Karl Ernst von Baer, 1792-1876) flow principles, i.e. finding that rivers of the north hemisphere, with north-south flows, more intensively erode their right riversides [28, 29].

Further analysed was the area covered by fluvial sediments of a particular groyne system (group of groynes that constitute the whole structure). Their areas varied from 3480 to 634 600 m^2 (on average 241 000 m^2) on the left bank, and from 3120 to 894 700 m^2 (on average 198 200 m^2) on the right observed bank. Regarding the distribution of groyne systems (fields) covered by sediments, it was detected that those systems placed on the left bank were more affected by fluvial deposition (6 ÷ 87 %, on average by 60 %) compared to groyne systems on the right bank (6 ÷ 74 %, on average by 40 %) (Tab. 1).

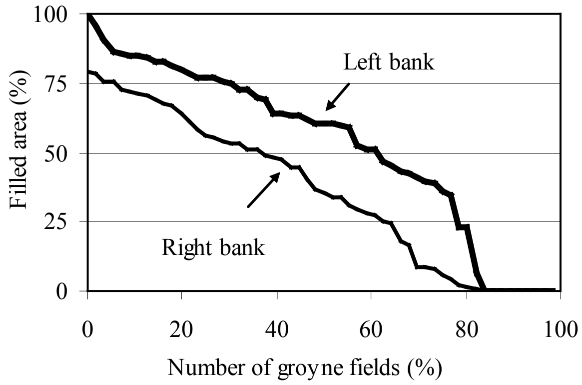

Figure 4 Distribution (%) of particular groyne fields covered by fluvial deposit materials on the left and the right bank of the Danube R.

Based on data shown in Tab. 1, grouping (clustering) of groyne systems was performed according to their area covered by fluvial deposits. Formed clusters show that in most of the groyne systems (8/25 or 32 %) total area of groyne fields was covered by fluvial deposits by 40 ÷ 60 %. In 7/25 or 28 % of observed groyne systems, fluvial sedimentation covered groyne fields by 60 ÷ 80 %, whereas in the rest of three clusters (i.e. field area covered with sediments by up to 40 % and >80 %) abundance of groyne systems was substantially lower (<20 %) (Fig. 5). Furthermore, in groyne systems (clusters) where sedimentation processes covered >40 % of the total groyne field area, the presence of perennial (forest) vegetation was also observed. On groyne fields with deposited area >50 % the connection of particular groyne field areas with banks was observed, thus the formation of a new bank. In 56 % of the groyne systems the fluvial deposition was not detected in one or more groyne fields at the measured water levels.

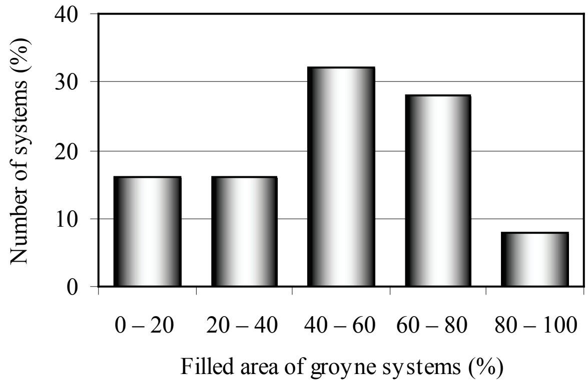

Figure 5 Classes (clusters) of groyne systems organised by proportion of fluvial deposition in groyne fields

Table 1 Total and deposited (filled with fluvial deposit materials) area of groyne fields (systems) on observed course of Danube R.

Station (km)	LEFT BANK		
	Total area	Deposited area	
	000 m²	000 m²	%
1424+700 ÷ 1422+000	732,3	492,7	67,3
1420+250 ÷ 1419+450	150,5	97,2	64,6
1398+250 ÷ 1396+900	270,0	160,3	59,4
1388+250 ÷ 1387+700	951,1	490,7	51,6
1381+100 ÷ 1378+500	574,7	201,6	35,1
1361+500 ÷ 1361+000	59,4	3,5	5,9
1349+830 ÷ 1349+300	798,9	634,6	79,4
1297+780 ÷ 1296+340	217,1	171,4	79,0
1294+910 ÷ 1293+240	178,2	143,0	80,2
1291+690 ÷ 1288+550	632,3	547,6	86,6
1284+335 ÷ 1283+200	149,7	104,2	69,6
1281+530 ÷ 1281+000	175,4	70,6	40,3
1273+010 ÷ 1272+200	36,5	16,2	44,3
	Minimum	3,5	5,9
	Maximum	634,6	86,6
	Average	241,0	58,7
	Total	3133,6	-

Station (km)	RIGHT BANK		
	Total area	Deposited area	
	000 m²	000 m²	%
1433+000 - 1429+000	226,1	78,8	34,9
1428+900 ÷ 1428+425	298,0	82,6	27,7
1422+100 ÷ 1420+800	192,7	112,3	58,3
1409+300 ÷ 1408+100	52,0	3,1	6,0
1368+380 ÷ 1367+080	465,7	247,8	53,2
1361+100 ÷ 1359+850	366,8	271,2	73,9
1309+500 ÷ 1308+100	132,3	32,1	24,3
1292+440 ÷ 1291+210	168,5	26,2	15,5
1287+210 ÷ 1286+080	110,1	63,4	57,6
1276+940 ÷ 1274+260	360,2	64,9	18,0
1272+560 ÷ 1268+570	1899,7	894,7	47,1
1265+050 ÷ 1261+650	806,6	501,5	62,2
	Minimum	3,1	6,0
	Maximum	894,7	73,9
	Average	198,2	39,9
	Total	2378,5	-

Finally, undoubtedly by using of commercial satellite or aero-photo images with smaller scales and higher resolutions it would be possible to obtain more accurate analyses of observed groyne systems in this study. Moreover, by employing certain filtering, stereoscopic and echo-probe techniques (during recording and/or data processing) more details on studied area could be detected (e.g. amount and level of sediment material, type of vegetations etc), and furthermore used for GIS database, i.e. studying of temporal changes in groynes. However, in this study we have demonstrated that exploiting public domain data could be one of very promising and cost effective approaches for environmental risk assessment of groyne systems of the analysed Danube R. course.

4 Conclusion

Based on the area of groyne fields covered by river sediment materials, in general it can be concluded that the observed groyne systems of the Danube R. section from Novi Sad to the border of Croatia, Serbia and Hungary, have markedly complied with the projected (planned) hydrotechnical measurements. By their construction, river erosion potential was substantially increased in its active (central) course, thus mitigating negative hydro-morphological processes in the vulnerable (marginal) riverside zones. Quantitative evaluation of fluvial sedimentation processes confirmed presence of >5,5 million m^2 (>3,13 million m^2 on the left and >2,38 million m^2 on the right bank) of newly formed area in groyne fields. Groyne systems constructed on the left riverside were substantially more (~60 %) affected by fluvial (in)organic deposition than those on the right observed bank (~40 %).

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