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ANTHROPOGENIC INFLUENCE UPON THE SUKIL RIVER BED FUNCTIONING

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Abstract. A river bed is a main indicator of the changes, including manmade ones that take place in their catchment basins. These changes are reflected in the river beds functioning, especially within the catchment basins located in the Ukrainian Carpathians. These basins have been noticeably affected by human impact during last century. The Sukil River (left tributary of the Svicha River) is one of them. By the relief morphology features and geologic-geomorphologic structure the Sukil River basin is divided into three parts: mountain, premountain and plain. The river bed within these three parts is characterized by noticeable difference in morphological and morphodynamical parameters. And the reaction of the riverbed on the manmade changes also is different in all three parts. First of all, it is a deforestation, agriculture, unauthorized gravel intake within the river bed and floodplain, river bed straightening, river bank consolidation and flood protection dikes constructing, melioration and ponds constructing etc. Research results ascertained noticeable difference between manmade influences in different parts of the catchment basin, especially the effects on the river beds and their functioning. In the mountain part the moderate impact dominates and is mainly presented by timber falling which has caused significant sediments runoff increasing during the floods of 2008 and 2010. In the premountain part the strongest impact is done by the unauthorized alluvium mining in the river bed. It caused increasing in the river bed morphodynamics and reinforcing of the linear and local side erosion. The erosion processes threat the roads and buildings within the river valley. The plain part of the river basin is most transformed. The river bed strengthening is carried out since the middle of XX-th century which was accompanied by the dikes and drainage network constructing. As the result many boggy areas were drained, the morphology of the Sukil river bed was changed, the meander process was stopped. But the tendencies to renaturalization of the river valley are observed during the last years. Conducted research are important for the rivers renaturalization and providing the strategy of sustainable development in Ukraine in the matter of natural resources protection and management.

Key words: channel morphodynamics; Sukil River; anthropogenic influence; mountain, premountain and plain parts of the basin.

АНТРОПОГЕННИЙ ВПЛИВ НА ФУНКЦІОНУВАННЯ РУСЛА РІЧКИ СУКІЛЮ

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Анотація. Русло річок є головним індикатором змін, зокрема, й антропогенних, що відбуваються у їхніх басейнах. Ці зміни особливо відображені у функціонуванні русел річок, басейни яких частково чи повністю знаходяться у межах Українських Карпат, які упродовж останнього століття зазнали значного антропогенного впливу. До таких басейнів належить р. Сукіль – ліва притока Свічі. За особливостями морфології рельєфу, геолого-геоморфологічної будови басейн Сукілю поділено на три частини – гірську, передгірну та рівнинну. У цих частинах басейну русло має суттєві відмінності у морфології і морфодинаміці русла та по-різному реагує на антропогенні зміни, що відбуваються в басейні. Головно, це – вирубування лісів, сільськогосподарське використання земель, несанкціонований забір алювію з русла та заплави, спрямлення русла та спорудження берегоукріплювальних споруд і протипаводкових валів, меліорація та створення штучних водойм та ін. Дослідженнями встановлено суттєві відмінності антропогенного впливу у різних частинах басейну Сукілю, виявлено їхній вплив на русло та його функціонування. В гірській частині домінує опосередкований вплив, зокрема, через лісозаготівлю, що викликало значний стік наносів під час паводків 2008 та 2010 рр. У передгірній частині максимальний антропогенний вплив створений несанкціонованим забором алювію з акумулятивних форм у руслі, що спровокувало збільшення його морфодинаміки та посилення локальної бокової та лінійної ерозії. Бокова ерозія в кількох місцях створила загрози руйнування доріг та міської забудови. Рівнинна частина басейну найбільше трансформована діяльністю людини. З середини XX ст. відбувається спрямлення русла, що супроводжувалось будівництвом протипаводкових дамб, створено мережу меліоративних каналів та штучних водойм. Це спричинило осушення боліт на заплаві та межиріччі Сукіль–Свіча, зміну морфології русла Сукілю, зменшення його звивистості. Фактично спричинило припинення процесу меандрування, який останніми роками відновлюється. Проведені дослідження є важливими для ренатуралізації річок та підтримки стратегії сталого розвитку в Україні, у сфері збереження природних ресурсів та раціонального управління ними.

Ключові слова: морфодинаміка русла; річка Сукіль; антропогенний вплив; гірська, передгірська, рівнинна частини басейну.

Introduction. The Sukil River is located in the Skole Beskyds (Ukrainian Carpathians) and Precarpathian Highland. Such location determines different morphology of the river bed, character of the river bed processes development and different impacts of human activity in the catchment basin. Generally, the problems of the human activities influence on the river beds and catchment basins are fully considered in the papers of I. Kovalchuk, L. Dubis, A. Mykhnovych, N. Habchak, O. Pylypovych, V. Skrypnyk, Kh. Volos, O. Palanychko and others with the central attention on the environmental-geomorphologic analysis of the fluvial systems.

In Ukraine the research of manmade impacts on a small river bed usually concerns the assessment of certain objects. As the study sites the settled and economically developed territories are mostly chosen. And the main scientific topic of research is a different way influence of the human activity upon the ecological state, functioning regime and morphodynamics of the river beds (the scientific papers of L. Dubis, M. Romashchenko, D. Savchuk, M. Nastiuk, I. Kovalchuk, T. Pavlovs'ka, G. Bayrak, P. Horishnyi, O. Obodovs'kyi, S. Tretiak, N. Rybak and others). Also, the detailed investigations of the gravel pit influence upon the horizontal and vertical deformations development in the Upper Dniester headwaters and the Yablun'ka River were carried out by A. Mykhnovych, O. Pylypovych 2017; A. Mykhnovych, O. Pylypovych, I. Chikova 2016; A. Strużyński A. Mykhnovych, O. Pylypovych, Florek, 2017. The results of these researches are correlated with our results of the Sukil River studies.

In the abroad publications these problems are studied more detailed on the example of some typical rivers (Surian, 2006; Billi & Rinaldi, 1997; Calle, Alho & Benito, 2017). Most of the studied rivers in Europe are characterized by the high level of manmade transformation and the projects on their renaturalization. The overall value of manmade impacts on the river bed and its morphodynamics is given by B. L. Rhoads 2020. The author analyses the influence of the agriculture (especially plough fields) on the river catchment as well as considers the effects of deforestation, gravel-pit intake, urbanization and engineering constructions etc on the river bed processes and stability. The important aspects of the investigations (Rhoads, 2020) are the impacts of a water reservoir on the sedimentation and also the influence of the climate changes on the river bed morphodynamics. The detail analysis of the manmade impact on the certain mountain rivers morphodynamics is presented also in the papers of N. Surian 2006; P. Billi, & M. Rinaldi 1997; J. A. Jones, & G. E. Grant 1996; M. Calle et al. 2017; R. B. Thomas & W. F. Megahan 1998 and others. To understand the functioning of the mountain and premountain river systems it is important to study the role of forests in the runoff forming within the watershed. It is well presented in the papers of O. Chubatyi, V. Oliynyk, O. Pylypovych, I. Kruhlov, H. Bayrak, A. Brown, Bingbing Ding and others. Deforestation impacts moderately on the river bed morphodynamics by the water and sediments runoff changes, hydrological regime fluctuations, the recent relief forming processes (A. Brown, R. L. Beschta, P. Tretiak, H. Krynyts'kyi, A. Deyneka, O. Pylypovych, A. Mykhnovych, I. Kovalchuk).

The objectives of this research are studying of different kinds manmade influences on the Sukil river bed, its morphodynamics and functioning. Special attention is paid to the gravel intake within the river beds, timber felling on the catchment slopes, erosion protecting and melioration constructing, transport infrastructure etc. The main task is assessment of the space differentiation of the manmade impacts on the river bed in different parts of the Sukil river basin – mountain, premountain and plain.

The methods of research. The investigations were conducted applying GIS technologies, remote sensing data and field investigations. The forestation dynamics, unauthorized gravel intake, engineering constructions localization were analyzed by the satellite images Landsat since 2006 until 2021. Satellite images were analyzed with the QGIS software and GoogleEarthPro resources. The historical topographical maps of the years 1880, 1929, 1959, 1978, 1989 were used for assessment of forestation, land use structure, melioration network and flood protection constructing. The hydrological observation data of the Tysiv gauging station for the period 1959–2021 have been analyzed. Verification of the results was done by the field investigations. Some additional influence factors were ascertained during the expeditions.

Results and discussion. Based on the topographical maps, satellite images and field investigations data the manmade impacts on the Sukil river bed have been classified into several groups. For example, according to the impact character – 2 groups are defined: direct and moderate; according to localization – areal, linear, local, and point (Table 1). The direct group includes gravel pits, erosion and flood protection engineering constructions, bridges. Moderate impacts group includes economical activity impacting upon river basin functioning (water and sediment runoff first of all): agriculture, melioration, timber falling, settlement and so on (Table 1).

According to the relief features and geologic-geomorphologic structure the Sukil river basin is divided into three parts: mountain, premountain and plain. Mountain part occupied the river catchment within the Carpathians (Sukil and Kozakivka villages). Premountain part is presented by the river basin between Kozakiv and Bolekhiv. And the plain part is located between Bolekhiv and Lany Sokolivs'ki village. Every part concerns to certain type of the river bed. The mountain part is characterized mostly by rapids and waterfalls with undeveloped alluvial forms. The premountain type is characterized by furcated river beds, and the plain type is presented by the river meanders (Rybak, 2020; Dubis & Rybak 2021).

Table 1. Classification of the manmade impacts according to the character and type of demonstration in the different parts of the Sukil river basin

Type according the localization in the basin and river bed	Part of the river basin			Character of impact on the river bed
	Mountain	Premountain	Plain	
Areal	Agricultural land use	Agricultural land use	Agricultural land use	Moderate
	Settlements	Settlements	Settlements	
	Timber falling	Timber falling	-	
			Melioration (drainage)	
Linear		Flood dikes	Melioration (drainage)	Direct
			Flood dikes	
		River bed strengthening	River bed strengthening	
		Linear erosion protection constructions	Linear erosion protection constructions	
Local (point)	Bridges and pipe lines	Gravel intake	Gravel intake	
		Bridges and pipe lines	Bridges and pipe lines	

Timber falling. This type of activity includes deforestation, road tracking, soil erosion on the slopes, reforestation (Rhoads 2020). Deforestation causes the decreasing of water retention during the rains (Chubatyi, 1984); Oliynyk 2008, 2013). Hydrological effects for the catchments of different area also are different. For the large basin area rivers, the flood water peaks growing are not very noticeable (Thomas & Megahan, 1998; Beschta, Pyles, Skaugset, et al., 2000). But for the small water sheds the runoff maximum grows up very quickly and causes high floods (Jones & Grant, 1996).

Mountain part of the Sukil river basin a several times was submitted to the influence of great timber falling like in 1950–60 for instance (Tretiak, Krynyts'kyi and Deyneka, 2001) and also during the ends of 1990. Analysis of the data of the Lviv Regional Center of Hydrometeorology for the period 1959–2021 (Fig. 2) has shown three periods of large water runoff parameter in the Sukil river bed – 1968–1975, 1979–1985, and 2004–2011. During these periods there were some extreme flood events in the river basin (for example in 1969, 1974, 1991, 2004, 2008, 2010 (Fig. 2). The main causes of the extreme floods forming were high intensity and large amount of precipitation and deforestation (Chubatyi, 1984; Pylypovych & Kovalchuk, 2017).

The key significance for the situation change was the moratorium for timber export into EU in 2015. A few of state programs concerning timber falling limitation and regulation in previous years had not noticeable effects. This fact is proved by our analysis

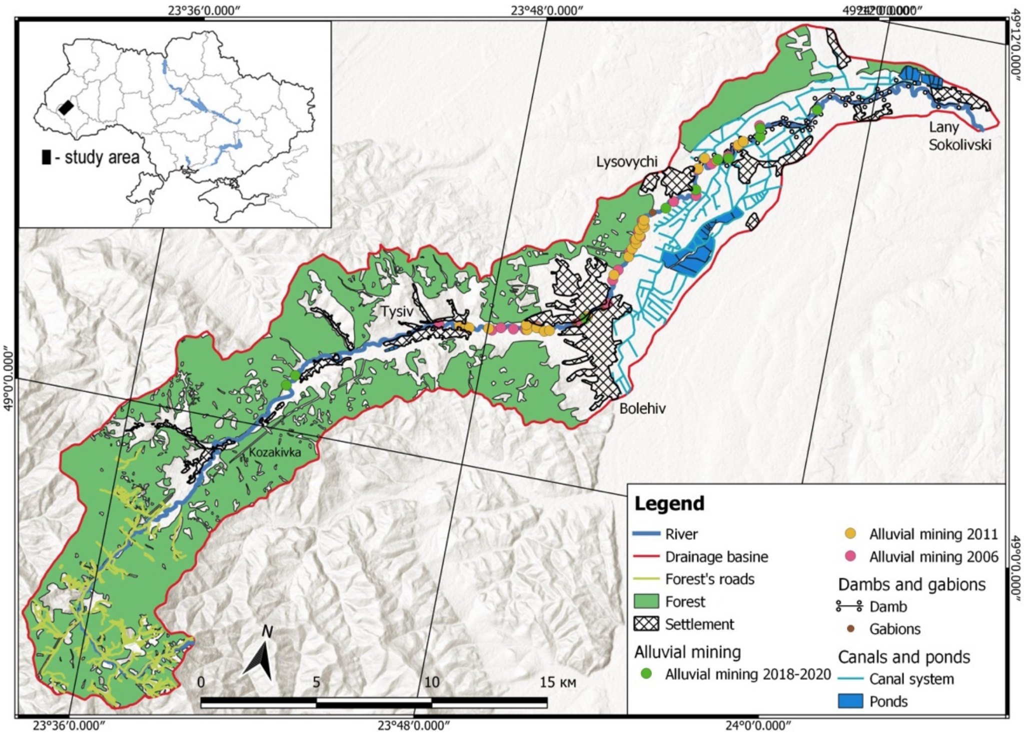

Fig. 1. Map of the factors of manmade impact in the Sukil river basin

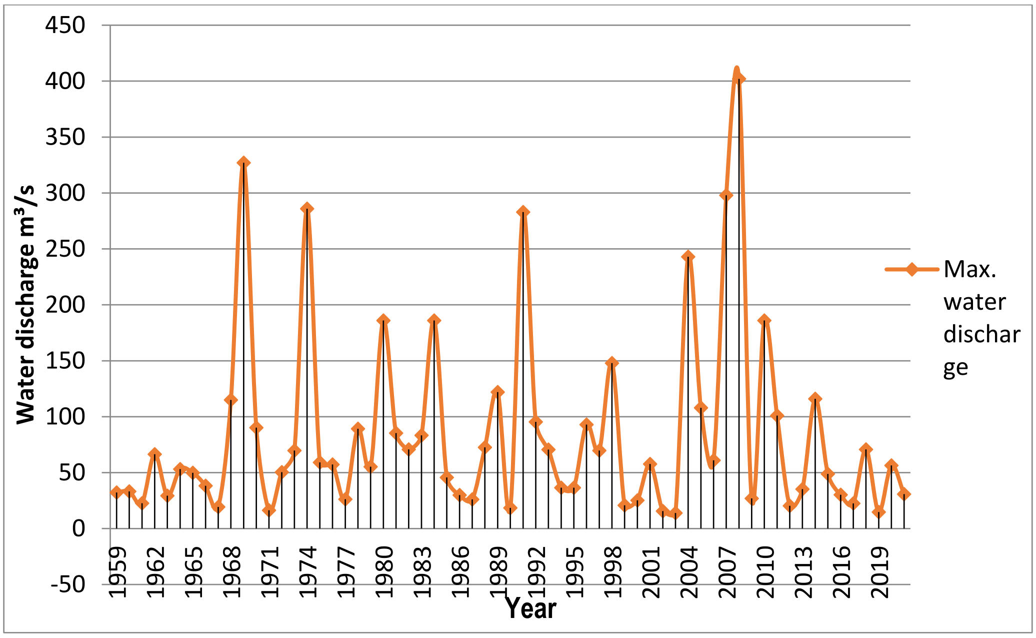

Fig. 2. Maximal water runoff in the Sukil (Tysiv) gauging station during 1959–2021 (according the data of the Lviv Regional Center of Hydrometeorology)

of the satellite images Google Earth of high resolution for the period 2006–2021. This analysis allows to defined two periods of timber falling in the Sukil river basin.

The first period lasts from 2006 till 2016 and is characterized by intensive timber falling – 782 ha or 14 % of the whole forest area in the mountain part of the Sukil river basin. The overall deforested area amounts 1264 ha (it is about 8,5 % of the total forest area in the studied river basin. This period correlates with the highest floods in the region (2004, 2008 and 2010).

The second period 2016–2021 is characterized by noticeable decreasing of the deforested areas (only 104 ha, 0,7 % of the whole forested area of the river basin. The cause of this decreasing is mentioned already moratorium for timber export in EU in 2015.

On the timber falling areas usually heavy machines works. Such practice causes intensification of the soil erosion. The total length of the timber roads within the mountain part of the Sukil river basin amounts 115,8 km the road density is approximately 1,91 km/km^2 (2020). This is quite high quantity taking into account the absence of the big villages in this part of the river basin. Heavy machinery causes microrelief changes, erosion ravines and gullies as well as increase in sediment load in the river beds (Beschta, 1978; Pylypovych, 2000, Pylypovych et al., 2010, 2013).

On the satellite images of years 2011 and 2020 (Fig. 3) the roads for heavy timber machinery are very good seen as well as the exogenous processes which develop due to these machines using on the slopes without soil recultivation. The horizontally provided roads which are not in use already are grown up by vegetation very soon. The roads along the slopes are characterized by intensive linear erosion and are not grown up by the plants (Fig. 3c). Such processes are observed also on the deforested slopes (Fig. 3b). Flat erosion makes the turf cover forming impossible and provides sediments load in the river bed. Some gray spots which are oriented along downstream on the slope are clearly observed on the satellite image of the year 2020 (Fig. 3b). These are the sites without vegetation cover after 9 years passed since timber falling.

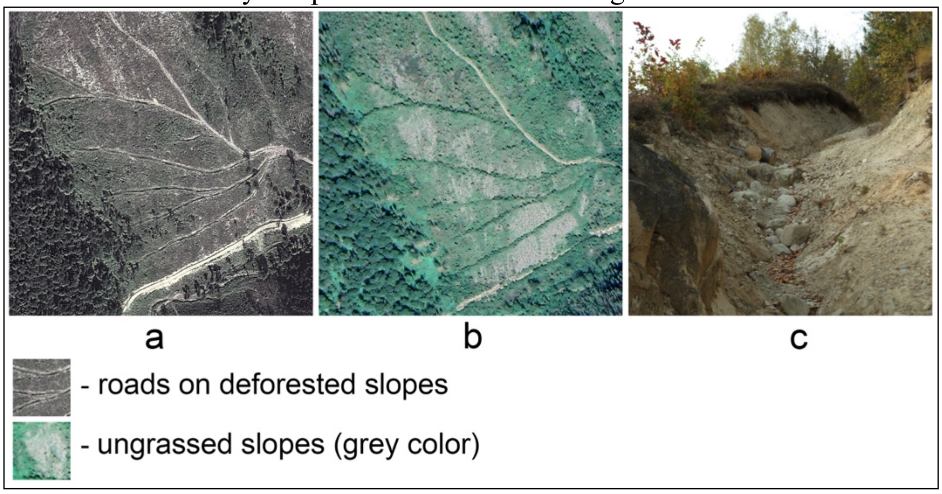

Fig. 3. Satellite images of the deforested slope in the mountain part of the Sukil river basin and gully erosion (*a* – 2011; *b* – 2020 p; *c* – linear erosion through the road near Tysiv village

Besides the linear erosion development on the deforested slopes the sheet erosion washout is observed very often. Somewhere it is combined with small landslides and mudflows which cause flash earning of the large amounts of sediments load in the river beds.

The natural factors (high slope inclination, cutting of the slopes by the river beds and so on) combined with unpractical timber falling and high precipitation amounts in 2008 and 2010 caused the earning of large quantity of the sediments load in the river beds (Fig. 4).

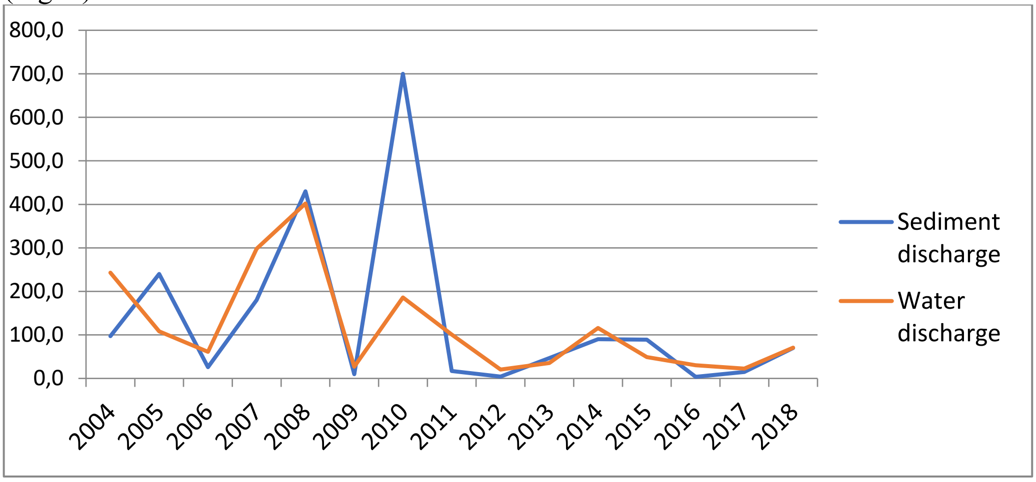

Fig. 4. Maximal yearly water and sediments runoff during the period of 2004 – 2018 (according the Lviv Regional Center of Hydrometeorology)

The coefficient of linear correlation between the year water discharges and sediments runoff for the Sukil (Tysiv) gauging station is small and amounts 0,323. But it should be taking into account some inertness of the basin system reaction on the forest area change. For example, the sediments runoff increasing is observed with some delay in a few years (Pylypovych, 2007; Pylypovych & Kovalchuk, 2017; and others). Some part of the sediments is accumulated also during the low water levels and then is transported again during the high water. The sediments redeposition takes place in the river bed. From our point of view the main cause of the sediments runoff maximum in the year 2010 (Fig. 4), not in 2008 when the maximal water discharges were fixed, is redeposition of the sediments of 2008. In 2009 water discharges were minimal and did not have noticeable impact on the sediments which were accumulated in 2008 in the river bed and the flood plain. The sediments were not well fixed by plants. That is why the flood 2010 caused their intensive washing out, transfer and accumulation in the furcated segment of the Sukil river bed. The carried-out investigations (Dubis & Rybak, 2021) demonstrate the significant river bed morphology changes in the furcated parts after the flood 2010 and forming of a lot of new accumulative forms and alluvial sediments in the river bed and the flood plain. Also, during the flood 2010 the maximal horizontal deformations of the river bed have been observed – up to 270 м (Dubis & Rybak, 2021). The similar quantity of the horizontal deformation was ascertained also for other rivers in the Upper Dnister river basin (Mykhnovych & Pylypovych, 2017; Mykhnovych et al., 2016).

Agriculture. Since the part of the Sukil river basin occupies the mountains and another in part of the river basin with the villages part is located within the plain are the agriculture also is different in them. In the mountain part of the basin within the villages Sukil, Kozakivka, Bukovets', Polianytsia, Bubnyshche, Tysiv the actively used in the agriculture field areas amount about 7,3 km^2 or 7 301 ha and are divided in many small fields with area less than 1 ha. Large areas of agricultural lands are used for pasture and haying. The plough fields are located within the relatively flat areas not far from villages and have form of the long rectangle.

Another situation is in the plain part. The total area of the used agricultural lands amounts 22,93 km^2. It is mostly plough fields. Most of them are used by agricultural holdings and farmers and have area up to several hundreds hectares.

There is no significant impact of the agriculture on the river beds and floodplains in the mountain part. In the plain part the system of melioration was constructed and the interfluvial bogs between the Sukil and Svicha were drained in the second half of the XX-th century.

The strongest impact of the agriculture is presented by high intensity sheet erosion during heavy rains in the period of crops growing. In this period the soils are not covered by vegetation. This caused earning of the sediments in the river beds and water turbidity increasing. Agriculture also is accompanied by a high amount of nutrients input in the soils. The nutrients affect the chemical composition of the river water.

Settlements. There are 13 settlements in the Sukil river basin. Their total area is about 114,28 km^2, but the area of built territories calculated based on the GoogleEarth high resolution satellite images is smaller – 20,37 km^2 (Table 2). The villages Bolekhiv, Sukil, Kozakivka, Lysovychi are located directly along the Sukil river and floodplain causing distribution of the roads, unauthorized dumps and gravel pits, bridges, flood protection and erosion protection constructions and so on.

Gravel pits exploitation. River bed alluvium, mostly gravel and sand, is a valuable material in the building and industry. Alluvium is well sorted and ready to use. It is mined in the river beds, floodplains and low terraces. Gravel mining is one of the leading factors of the river bed morphology and dynamics changes (Rinaldi et al., 2005; Mykhnovych & Pylypovych, 2017; Mykhnovych et al., 2016).

In the Sukil river bed the gravel mining is unauthorized except the cases of river banks stabilization measures and is carried out by non-industrial methods (Dubis & Rybak, 2021). Usually gravel mining is realized on the floodplain and banks or shoals. This makes the effects of mining on the morphodynamics less significant in comparison with the mining directly in the river bed (Rinaldietal., 2005).

Investigations of the gravel mining in the Sukil river bed were carried out in three-time sections – 2006, 2011, 2018-2020. In 2006 the 27 gravel pits were fixed (Fig. 1), the small and very small sized (a few m^2), and large (with the area of more than 5000 m^2 as well (Fig. 5). The main part of the alluvium mining is located near the settlements Tysiv and Bolekhiv, where the river goes out of the mountains on the foothills and is characterized by the furcated type of the river bed with the numerous accumulative forms. Some local gravel pits are located along the river bed near Lysovychi village.

In 2011 the amount of gravel pits was 25. The locations were same as in 2006 but the most part of mining was concentrated between the settlements Bolekhiv and Lysovychi. The mining was done in the river bed shoals, had a spontaneous character and can be seen on the satellite images up to 2020. On the satellite images of the years 2015 and 2020 the accumulative forms renewing is observed. This renewing is caused by the intensive sediments transportation during the floods (Fig. 5).

Gravel mining from the river bed shoals and floodplain causes negative relief forms (Fig. 6A), which act during the floods like water rejecting reservoirs and make the flood peak lower (Fig. 6B) (Rinaldi et al., 2005). At the same time, they accumulate also the sediments. These processes help to renew the natural state of the river bed (Fig. 6C) and cause erosion development downstream (Rinaldi et al., 2005; Calle et al., 2017; Mykhnovych & Pylypovych, 2017).

Table 2. Settled area in the Sukil River basin

Settlement	Settled area, km^2 (according to the Google Earth satellite images data)	The total area of the settlement area, km^2
Bolekhiv	10,157	36,69
Tysiv	2,044	7,285
Zaderevach	1,829	6,7
Lysovychi	1,65	18,5
Lany Sokolivs'ki	1,067	8,55
Kozakivka	0,727	4,245
Uhilnia	0,673	8,66
Polianytsia	0,58	-
Velyki Didushychi	0,539	21
Bubnyshche	0,365	-
Sukil	0,323	1,15
Mizhrichchia	0,243	-
Bukovets'	0,15	1,5
Total area	20,347	114,28

Fig. 5. Alluvium mining in the river shoal near Tysiv in 2006 (the mine area is 6 956 m^2; the volume is more than 3 478 m^3); the river bed type changes due to the alluvium mining in 2011; the natural river bed recovering in 2015

According to the satellite images of 2020 and field investigations there were no unauthorized gravel pits. But some separate pits were found near Polianytsia, Bolekhiv, Lisovychi, Zaderevach. In the year 2020 the tendency of decreasing in gravel mining is observed. The main cause of such decreasing is reinforcement of the responsibility for unauthorized gravel mining and rising of the citizen's consciousness and education.

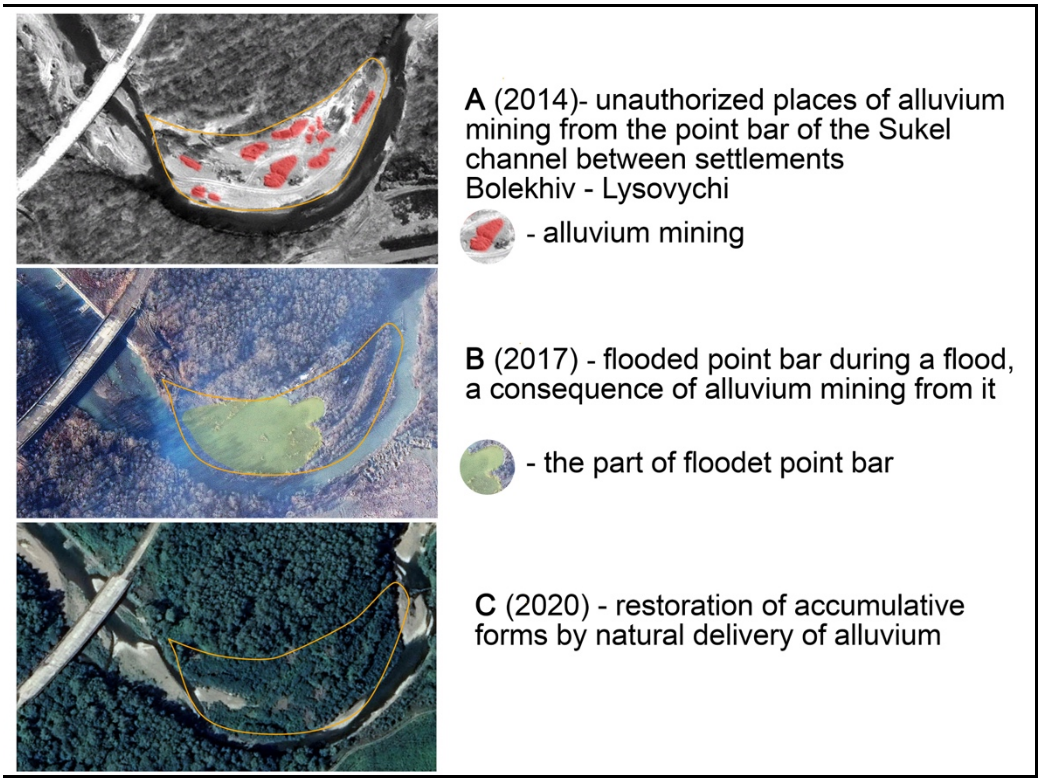

Fig. 6. Alluvium mining from the river bed shoals (A), mining impact on the water flow character during the flood (B), renewing of the natural state of the accumulative form (C)

Flood protection and erosion protection engineering constructions. Since the middle of XX century the river bed and bog territories in the premountain and plain parts of the Sukil river basin were continuously meliorated and regulated. In 1950th – 1980th the drainage system with many sluices were constructed to regulate the water runoff. Also, the cascade of ponds between villages Lysovychi and Mizhrichchia were built in the Sukil – Svicha interfluve for the Herynia stream regulation (Fig. 1). A few channels connect the ponds with the Sukil river and lower the flood peaks. The total ponds area is about 250 ha. The total length of the melioration channels amount 102,8 km, the density of the melioration network – 0,97 km/km^2 with asymmetry between the left and the right banks. The channel density of the right-side amounts 1,47 km/km^2. On the left side this parameter is 0,48 km/km^2. It is caused by the bog ares in the Sukil – Svicha interfluve and non-satisfactory state of the melioration network. Some channels are overgrown by vegetation and also are characterized by non-satisfactory state. During last years the tendency to renewing the channels is observed. Some channels were cleaned, the water connection between the ponds and the Sukil river bed was recovered. Drainage system affect on the river alimentation by the ground waters as well as on its hydrological regime.

In 1980th the system of flood protection in the plain part of the river valley was constructed between villages Lysovychi and Lany-Sokolivs'ki. The dikes caused the decrease in the meander belt width from 150 to 300 m. The meander coefficient has decreased from natural 1,5 in the start of XX-th century to 1,3 in 1990. But now the river step by stem comes back to the natural state. In the studied river segment the destroying of the dike by side erosion was detected in four places from 100 to 200 m (Fig. 7). The meander coefficient has increased up to 1,36 in 2020 (Rybak & Dubis, 2021). It is important to mention that the river bed strengthening and natural dynamics of the Svicha River (it is a natural erosion basis for the Sukil) caused the significant changes in the Sukil river mouth localization (Rybak et al., 2021).

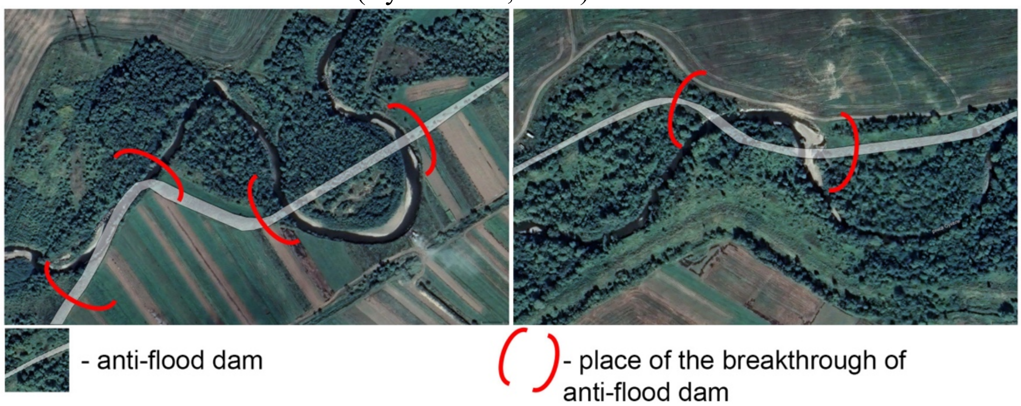

Fig. 7. Places of the dikes breaking in the lower stream of the Sukil river

The extreme flood in the July 2008 has destroyed 2 anti-erosion constructions in Tysiv village and Bolekhiv town. The side erosion damaged the transport infrastructure and houses located there. It provides to build the bank reinforcing engineering like gabions. The constructions with the length of 120 m were built on the furcated river bed segment near Tysiv in 2011 and 2015 and near Bolekhiv town with the length of 120–165 m in 2019 and 2020 (Fig. 8).

In the places of gabions partly straightening river bed processes are observed. The gravel mining for gabions constructing caused the local regressive erosion cutting of the river bed.

Conclusions. The results of the manmade impact on the river functioning analysis have testified about significant differences in the mountain, premountain and plain parts of the river basin. In the mountain part the moderate impact dominates and is

Fig. 8. Erosion-resistant constructions in Bolekhiv town

mainly presented by timber falling which has caused significant sediments runoff increasing during the floods of 2008 and 2010. In the premountain part the strongest impact is done by the unauthorized alluvium mining in the river bed. It caused increasing in the river bed morphodynamics and reinforcing of the linear and local side erosion. The erosion processes threat the roads and buildings within the river valley. The plain part of the river basin is most transformed. The river bed strengthening is carried out since the middle of XX-th century which was accompanied by the dikes and drainage network constructing. As the result many boggy areas were drained, the morphology of the Sukil river bed was changed, the meander process was stopped. But the tendencies to renaturalization of the river valley are observed during the last years.

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