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Riverbed stability assessment under Lithuanian conditions

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Abstract

In many cases riverbed self-regulation processes are similar in natural and canalized channels, however dynamic equilibrium is steady in natural rivers, while hydrodynamics processes are in progress in regulated ones. Prof. Grischanin's criterion M was used as one of the criteria to evaluate bed stability of natural and regulated rivers. This hydrodynamics criterion is widely known and used in large rivers of the former USSR, but it has not been sufficiently studied under Lithuanian natural conditions. The following research showed that values of this criterion are close to 1 (0.9 +/–0.12) in small natural rivers of Lithuania, and much lower or higher in regulated ones. This indicates that the natural riverbeds are relatively stable, while recovery processes of riverbeds are still in progress in canalized streams. We consider that Grischanin's stability criterion M could assess recovery level of river beds.

Keywords: regulated streams; rivers bed stability; Grishanin's criterion.

1. Introduction

Many Lithuanian natural streams have been deepened and straightened artificially, i.e. they have been regulated by improving drainage function during land reclamation process. For this purpose such rivers were further maintained and managed. That influenced negatively their bed stability and hydrodynamic equilibrium for canalized rivers. However, at the same time, natural rivers bed recovery processes were observed during the decline of the maintenance of regulated streams what affected their stability.

At the same time natural rivers, as unique natural systems, are able to modify and adapt their beds form, sediments and the longitudinal slope (as opposed to artificially adjusted and enhanced bed). Rivers have an ability to do it over a sufficiently long period of time while changing both, a bed form as well as its position in the plan, regulating the bottom surface roughness and sediment leaching and deposition [1]. Self-regulation processes of natural streams take a long time under stable climate conditions. These processes let to evolve river into a stable constant width and depth of the beds in which the local flow accelerations change the slowdown, while the average velocities and longitudinal slope remain almost constant. An almost constant and comparatively stable energy loss of river flow at the same time stabilizes and remains constant.

Based on the research, Leopold and Rosgen [2] suggest that naturally formed rivers conform to their beds for the minimum energy expenditure in the natural environment due to self-regulation processes. This means that the flows of these rivers and their beds interaction process through a historically long period of time evolved towards a dynamic equilibrium in such a way that the current conditions of flow potential energy comparable loss of water and sediment transport would be the lowest [3]. Therefore, for any reasons, natural flow can also change its channels or adapt to new conditions, depending on the change of the water and sediment flow supply [1], [4]. This shows to both, the river bottom sediments form adaptation, as well as the bed forms and meanders changes on periodically flooded valley areas of vegetation cover change [5]. In some countries the river-bed stability development and adaptation to changes of flow and sediment transport condition patterns were examined mostly for natural medium size and large rivers only [5], [6]. Thus, to investigate, analyze and evaluate small canalized river bed deformation conditions as well as their riverbed processes intensity especially for Lithuanian conditions becomes very important.

The aim of research – to compare the stability of regulated and natural rivers beds.

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2. Materials and Methods

2.1 Objects of research

Research was carried out in three medium-sized Merkys Basin rivers: (Amarnia, Grūda, Spengla). Amarnia – the right tributary of river Merkys, flowing out from the lake Nedzingis. The total length of rivers investigated is 15.1 km and the catchments area – 144 km^2. The rivers are regulated from springs to 10 km. Grūda – the left tributary of river Merkys. The source of the river is in Grūda Lake in Belarusian forest, near the Lithuanian-Belarusian border. The length of this river is 36.2 km, the catchment area – 248.4 km^2. The river is regulated from spring to 22.2 km. Spengla – the right tributary of river Merkys. The length of the river is 25.9 km, the catchment area is 148.3 km^2. The source of the river is in Spengla Lake. The middle reaches of the river are adjusted (from 19.6 to 13 km). The object of research location map is shown in Fig. 1.

Fig.1. Sections of studied rivers in the Merkys river basin. The numbering corresponds to Table 1

Table 1. General environment parameters of the investigated section of the streams (RL - straightened section in field, NT - natural section in forest)

Streams	Sites N.	Section	Locality	Discharge, m^3/s	Average width, m	Average depth, m	Current velocity, m/s	River-bed overgrow with plants, %
Amarnia	1	RL	54° 15' 43" N, 24° 19' 52" E	0.83	5–7	0.5	0.3	15
	2	NM	54° 14' 21" N, 24° 21' 03" E	1.32	6–7	0.5–0.9	0.6	5
Grūda	3	RL	54° 01' 54" N, 24° 20' 14" E	0.92	5–7	0.4–0.6	0.5	20
	4	NM	54° 07' 05" N, 24° 19' 20" E	1.79	5–8	0.6–0.8	0.6	5
Spengla	5	RL	54° 23' 25" N, 24° 43' 12" E	0.58	6–8	0.5	0.3	15
	6	NM	54° 21' 07" N, 24° 47' 05" E	1.34	7–9	0.5–1.2	0.5	5

2.2 Methodology of research

Selected rivers bed sections were divided into cross-sections every 1 meter. Rivers bed width (b) and average bed depth (d) were determined in every cross-sectional area. Flow velocities and discharge were measured using acoustic device “StreamPro ADCP”. GPS GeoXH receiver was used to determine position in space (x, y coordinates) of “StreamPro ADCP” device in the open furrows. In cases where the woody vegetation covered bed and the use of GPS was not possible due to major errors, the geodimeter device was used, which data is coordinated by GPS device. Streams coastline was measured by GPS device or geodimeter.

Riverbed points (Fig. 1a) with flow velocity and depth values were interpolated by geostatistical methods with program ArcGIS 10.1. After that the bed depth and flow velocity surfaces (GRID) are received. With the help of these values the average of Froude number was calculated for the investigated sections of rivers. Froude number characterizes river flow kinetic and potential energy ratio in measured cross section. Froude number is defined as:

$$Fr = \frac{v}{(gd)^{1/2}}, \qquad (1)$$

here: v – the mean velocity in river cross section, m/s;
g – acceleration due to gravity, m/s^2;
d – the average bed depth in river cross section, m.

In order to assess the stability of the river bed channels the Grishanin's dimensionless rivers bed stability coefficient M was used [7–12]. The famous hydraulics professor analysed the well-established, slow-changing natural flow currents and found this hydrodynamics open alluvial bed stability criterion, which links the form of the river bed channel to the formative flow stream energy [8]:

$$M = \frac{d(gb)^{1/4}}{Q^{1/2}} = \left[\frac{d}{b}\frac{1}{Fr^2}\right]^{1/4} \qquad (2)$$

here: M – the Grishanin dimensionless rivers bed stability coefficient;
d – the averaged bed depth in river cross section, m;
b – the river bed width in river cross section, m;
Q – the bankfull discharge, m^3 /s;
g – acceleration due to the gravity, m/s^2;
Fr – the dimensionless Froude number.

Calculated values of the criterion M were compared with the study results of other researchers. Following the comparison of results the reliability of the criterion was analysed by using it to evaluate the relative stability of Lithuanian rivers.

3. Results and Discussion

River bed processes were evaluated according to the above mentioned methodology in the investigated reaches. The Froude number and river bed stability coefficient – Grishanin's criterion M – were used as the main characteristics to evaluate stability of natural and regulated rivers stretches. The relationships between these dimensions are shown in Fig. 2.

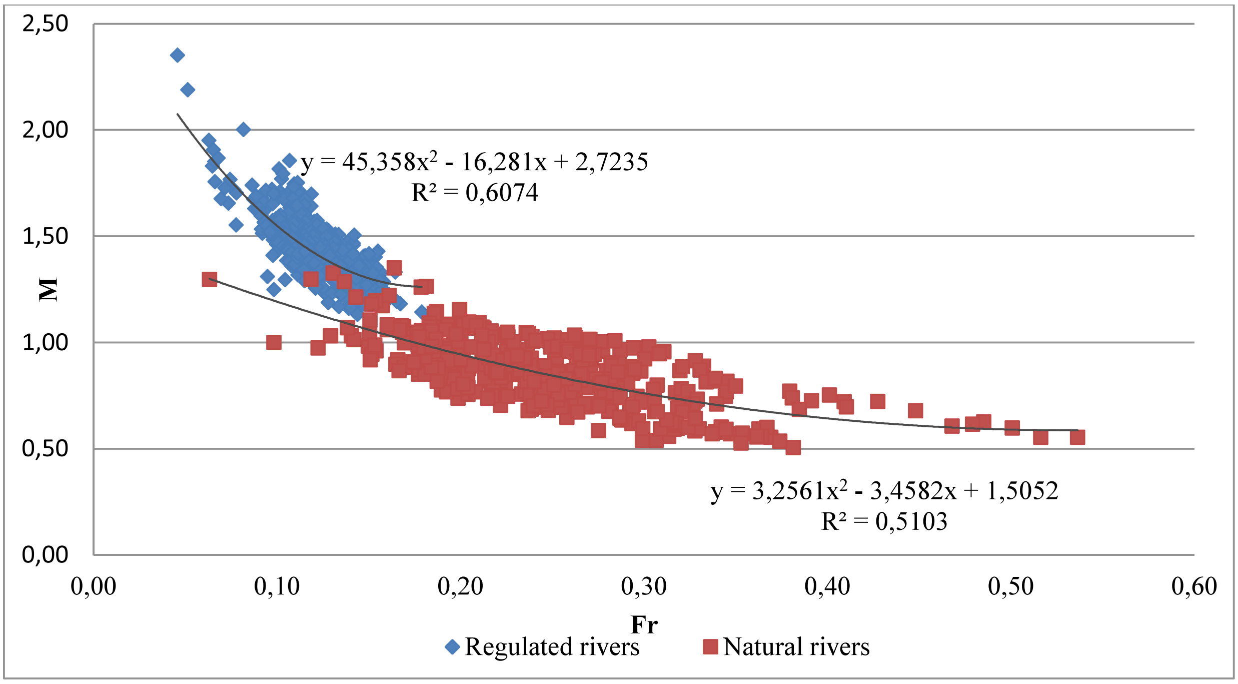

Fig. 2. Relationship between stability criterion M and Froude number Fr

Research data formed two evident areas where the data of natural and regulated rivers are spread as shown in Fig. 2. According to this data it could be confirmed that rivers bed stability and Froude number are totally different in natural and regulated rivers. The values of rivers bed stability criterion M vary from 1.13 to 2.35, the average of these data – 1.44 of last mentioned ones. The Froude number values differ from 0.05 to 0.18, the average – 0.12 of regulated ones. At the same time the values of natural rivers bed stability criterion M vary from 0.51 to 1.35, the average of these data – 0.86. The Froude number values differ from 0.06 to 0.54, the average – 0.25

In order to define relationship between river's bed stability and Froude number the determination coefficient $R^2 = 0.607$ confirm that correlation is moderate for regulated rivers. The values of regulated rivers spread in bigger area, so the determination coefficient $R^2 = 0.510$ shows that the moderate correlation was found.

According to K. V. Grishanin, the value of rivers bed stability criterion M is around 0.92 for stable rivers, when M > 1.1 for silt and sediment channels and then M<0.92 for erosion processes occurred.

Comparing these results with the boundaries of coefficient values presented by K. V. Grishanin one we can notice that silting and sedimentation processes are determined in canalized stream stretches. Meanwhile, the investigated natural rivers are close to the natural watercourses with occurring small erosion processes.

At the same time the values of Froude number for regulated rivers, comparatively less than in the natural ones, were found. That shows that natural streams are more rapid, shallow, stable and armoured comparing with regulated ones. So, the distribution of stream energy is more equal what does not let to silt their channels and keep river beds stable in natural rivers.

In order to evaluate the relationship between beds stability criterion, described as K. V. Grishanin's stability factor (M), and rivers width and depth ratio, the graph was created for natural and regulated streams (Fig. 3). Research data was compared with other researchers' data [13].

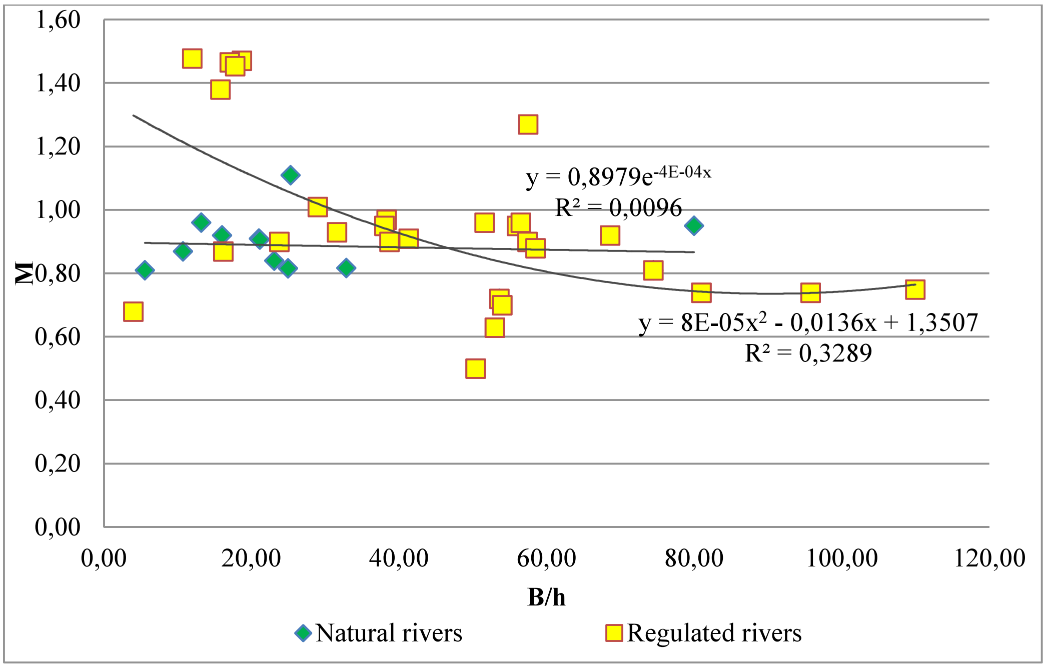

Fig. 3. The relationship of K. V. Grishanin's coefficient M values with width and depth ratio B/h in natural and regulated rivers

Mean values of K.V.Grishanin's criterion (M) ranged from 0.72 to 1.11 in investigated natural stretches. The average value is M = 0.89 of these sections. It means that natural rivers that were investigated are stable or near this condition. Mean values of width and depth ratio varies from 5.56 to 80, and average of these values is 33.06 for natural rivers. Actually, the B/h values ranging from 33 to 80 depend to largest rivers in Lithuania (Šventoji, Minija) and the rest part of the range (5.56–33.00) is characteristic for smaller streams (Amarnia, Spengla, Gruda).

The stability of regulated stretches is differing from natural ones. The values of stability criterion M vary from 0.50 to 1.48, but the average of means is 0.91, i.e., like stability of natural streams. It shows that most of the largest rivers of Lithuania that are named as regulated are really more natural. That could be explained, that regulation of largest rivers didn't change their condition totally, what happens with smaller ones. Thus it course has kept some natural and under stable conditions. Siltation and erosion processes that occurred in the rest part of the regulated rivers were fixed. These processes were set in small rivers (Amarnia, Gruda, Spengla), were the ranges of stability criterion were in-between 1.38–1.47. Another part of remaining data depends to largest rivers like Nemunas, Neris, Šventoji, where erosion processes dominate (M = 0.50–0.75). That related with energy of stream power distribution, as well as with velocity and other hydraulic parameters.

Width and depth ratio (B/h) for regulated rivers also fluctuate in wide range – from 4.00 to 110.00. This ratio for largest rivers is varying from 38.00 to 110.00. At the same time ratio values are less than 18.70 for small investigated rivers. It means that the largest riverbeds are relatively wider with some erosion processes ongoing in Lithuania. Small streams with narrow watercourses are tending to silt. That is confirmed by the research data.

According to the research carried out by other researchers [14] significant differences of K. V. Grishanin's coefficient between natural and regulated river beds were determined also. K. V. Grishanin's coefficient values for natural Kume and Maisys stream sections are 0.81 and 0.87, respectively. In the regulated Kume section the coefficient M value is only 0.68. These results show that the stability criteria M of natural watercourses compared to regulated sections are significantly closer to 1. However, the criterion M value is less than 0.90 for the researched rivers sections. This indicates that bed stability was insufficient in natural Maisys and Kume rivers (M = 0.87<0.92 and M = 0.81<0.92, respectively). Meanwhile, this stability criterion is only M = 0.68, i.e. 0.68 << 0.92 for the regulated Kume river section. This shows that the regulated section is very unstable, and it is still under intensive bed regeneration process. In that case the river bed will be able to stabilize naturally just over a sufficiently long period of time.

Comparing results published in the article and results of other researchers [14] there is a clear relation between the processes in natural streams and values of K. V. Grishanin's coefficient ranging from 0.81 to 0.91. Meanwhile, the average coefficient M values range – 1.43 and 0.68 in regulated sections from different studies. This shows that the sections with a higher value of M (1.43) can be silted, as more intense erosion processes with lower value of the M criterion (0.68) were observed in these sections.

Stability criterion has been tested for different soil conditions by other researchers, and all of them confirmed its reliability [13], [15], [16]. Their studies have shown that this stability criterion value varies depending on the river bottom soil, the banks overgrowth and bed meanders' length. For example, assessing the largest Lithuanian rivers, such as Nemunas, Neris, Sventoji and Minija their M value is equal to 0.915, so the rivers' state is close to the steady [13]. Submountain riverbeds formatted from large rocks are stable and at lower values of M [15] and the overgrown banks of the rivers also increase banks stability [16–18]. Thus, these studies confirm that the riverbed sediment size and banks overgrowth can affect bed processes.

It should be noted that K. V. Grishanin's bed stability factor also evaluates the river-bed physical environment balance. Further researches are appropriate to determine relation between the stability of the bed with living organisms and the influence on habitat formation. Such studies would allow better understanding of the relation between the physical environment of streams and water fauna.

4. Conclusions

The research clearly shows that river bed stability is totally different for natural and regulated rivers. Values of river bed stability criterion M for natural and regulated channels vary: 0.51–1.35 and 1.13–2.35, respectively. The results confirm that stability and small erosion processes dominate in natural streams while sedimentation and erosion processes are observed in regulated ones.

The Froude numbers Fr mean values differ from 0.12 in regulated rivers to 0.25 in natural ones. It shows that natural streams are more rapid, shallow, stable and armoured comparing with regulated ones.

The obtained results show that majority of the large regulated riverbed channels are stable enough, because their stability factor is near the 0.91, the same as of stabile natural streams. Those large rivers keep natural and stable riverbed form conditions in dynamics equilibrium conversely than smaller ones.

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