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ANTHROPOGENIC TRANSFORMATIONS OF RIVER VALLEY'S VEGETATION AND THEIR IMPACT ON PERCEPTION OF ECOSYSTEM SERVICES BY INHABITANTS. A CASE STUDY FROM THE KŁODNICA VALLEY (SILESIAN UPLAND, POLAND)

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Abstract

Over 200 years of anthropopressure had an impact on the abiotic and biotic environment of the Kłodnica valley, as well as on ecosystem services and the standard of living of its inhabitants. Vegetation of semi-natural section of the Kłodnica valley (Katowice) was created by species-rich and species diverse phytocoenoses of nitrophilous fringes (*Urtico-Calystegietum sepium*, *Alliaria petiolata-Valeriana sambucifolia* community), wet (*Alopecuretum pratensis*) and fresh (*Festuca rubra* community) meadows. The probability of flood was low. Anthropogenic section of the Kłodnica valley (Gliwice) was dominated by poor in species and low diverse communities of invasive (*Impatiens parviflora*, *Reynoutria japonica*, *Aster novi-belgii-Parthenocissus inserta*) and expansive plants (*Urtico-Aegopodietum podagrariae*, *Bromus inermis* community). The probability of flood was high. Provisioning (fresh water), regulating (climate, flood regulation), as well as cultural (aesthetic value of landscape and plant cover, recreation) services were degraded and in the opinion of the residents the valley needs revitalization.

Introduction

The development of human settlements has been inseparably connected with river valleys. The rivers have provided many important ecosystem services, including provisioning (e.g. food, water, timber, fiber), regulating (climate changes, floods, diseases, waste, water quality), cultural (e.g. recreational, aesthetic, spiritual benefits), as well as supporting (soil formation, photosynthesis, nutrient circulation) services (Millennium Ecosystem Assessment 2005). The intensification of urbanization and industrialization, which had begun in the 19th century, was accompanied by an increase in negative human interference in the river valleys. Some hydrotechnical works, including the straightening of riverbed, the artificial construction of flood embankments, melioration and drainage, have caused that riverine vegetation to be severely transformed or even completely destroyed. In addition, a considerable amounts of municipal and industrial wastewaters were discharged into the river, causing their pollution. The consequence of ecosystem degradation was the deterioration or even complete loss their ecosystem services (Bender et al. 2012, Everard and Moggridge 2012, Januchta-Szostak 2012, Sender and Maslanko 2018).

Vegetation seems to be one of the most sensitive component of the environment, that can be treated as indicator of changes in both biotic and abiotic conditions of the riverine ecosystem (Kowalska 2012). The anthropogenic disturbances of riverside ecosystems led to the synanthropization of existing vegetation. This is often manifested by growth in the number of communities, the spread of natural hemerophilous communities, the disappearance of the original species combinations, the creation of new, heterogeneous combinations of species, the emergence of poor in species and less diverse communities, and the lack of a dynamic balance expressed by many stages of degradation, regeneration and pioneer communities (Sudnik-Wójcikowska and Koźniewska 1988). Floodplain vegetation provides many ecosystem services, such as protection against soil erosion, water retention, macro- and microelements circulation, river self-purification, carbon sequestration, improvement of ionization and air circulation. In addition, it also has certain aesthetic value and serves as a place for recreation and tourism. One of the most significant consequences of strong transformations of riverine phytocoenoses is an increase in flood risks in heavy urbanized catchments (Hanczaruk et al. 2016, Hanczaruk and Kompała-Bąba 2016, 2017, Hanczaruk and Kulik-Knapik 2017, Kompała-Bąba and Hanczaruk 2017).

Kłodnica is an model example of river valley, which has been subjected to strong anthropopressure since the middle of the 19th century (ABSALON et al. 2007). From springs, located in Katowice, river flows through densely populated and industrialized towns of the Upper Silesia Industrial Region, such as Katowice, Ruda Śląska, Zabrze and Gliwice. It is transformed mainly by mining and processing of hard coal (DRĄG 2012). Below Gliwice, until its mouth in Kędzierzyn-Koźle, Kłodnica flows mainly through agricultural lands (OLKOWSKA et. al. 2017).

The aims of the study were:

– to recognize the diversity and distribution of the current vegetation of the Kłodnica valley being under different impact of anthropogenic transformations,

– to assess the flood risk in the investigated section of the Kłodnica valley,

– to assess the perception of ecosystem services provided by the Kłodnica valley by inhabitants, as well as the standard of living of the residents.

Material and Methods

Research sections of the Kłodnica valley

In order to show the influence of anthropogenic disturbances on the Kłodnica valley, two sections were selected, that differ in the structure of land use, the degree of the riverbed regulation, population density and the degree of synanthropization of vegetation. Their length was about 1.5 km.

The semi-natural section was located in Katowice (N 50°13'44", E 18°55'00) – Figure 1). The width of the Kłodnica valley reaches 100 meters. Kłodnica flows through unregulated or slightly regulated channel. The valley has numerous oxbow lakes and its area is characterized by the use of forest and agricultural land. The population density is 242 inhabitants/km^2, that valley being covered by a large dispersion of single-family buildings (CABAŁA and GREŃ 2002, *Otwarty Regionalny...* 2016a,b).

The anthropogenic section was located in Gliwice (N 50°17'20", E 18°41'06") – Figure 1). The development of industry and urbanization was accompanied by the regulation of the riverbed and concreting of its banks, as well as by removal of thickets and riparian forests, which naturally occurred along the Kłodnica valley from the beginning of the 18th century. Currently, densely populated areas (2081 inhabitants/km^2) are found near the Kłodnica valley in Gliwice. The landscape of the valley is dominated by compact urban and industrial buildings, didactic buildings of the

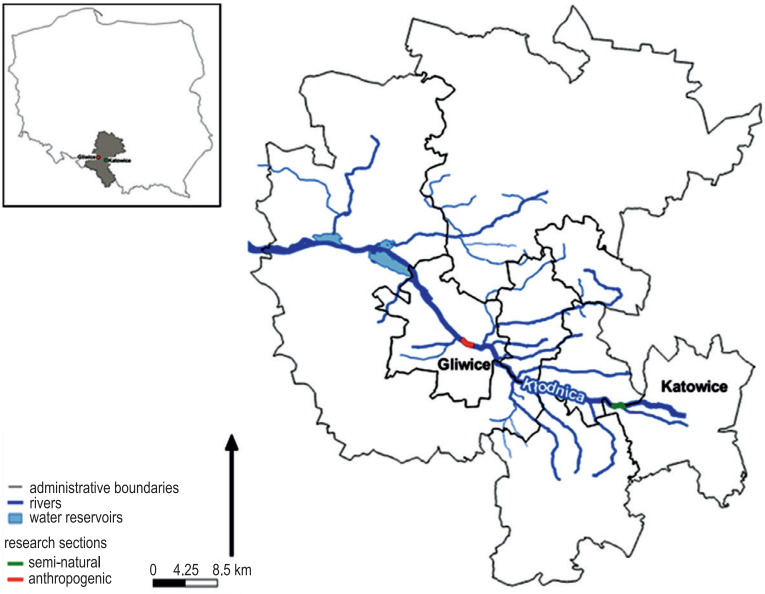

Fig. 1. Location of the research section on the background of the Kłodnica catchment map

Silesian University of Technology and sport, as well as recreational infrastructure. In the vicinity of the valley the city park occurs (*Otwarty Regionalny*... 2016a,b, Hanczaruk and Kompała-Bąba 2017).

Vegetation sampling

In the vegetation seasons 2014–2018, 151 phytosociological relevés were made along the studied sections of the Kłodnica valley using the Braun-Blanquet (1964) method in order to recognize the diversity of present vegetation. Relevés had an area of 25 m^2. The plant nomenclature follows Mirek et al. (2002). The invasive alien plant species were taken after Tokarska-Guzik et al. (2012).

Classification of current vegetation of the Kłodnica valley

Before further analyses, the quantitative-qualitative Braun-Blanquet scale used for vegetation sampling was transformed into percentage values according to the rules: *r* – 1%, + –2%, 1–3%, 2–13%, 3–38%, 4–68%, 5–88%. The data were classified using the unweighted pair group method with arithmetic mean (UPGMA) and the Bray-Curtis distance (Dzwonko 2007). The calculations were made for log transformed data. In order to assess the affinity of species to distinguished vegetation units phi coefficient of association as a measure of fidelity was used (fidelity values in the range from -1 to 1 were multiply by 100). Each vegetation units was described by diagnostic, constant and dominant species. As a diagnostic species of particular vegetation unit were considered taxa, for which the phi coefficient was higher than 20. Constant species were taxa with frequency above 40% and dominant ones with a coverage of more than 25% in at least 15% of phytosociological relevés (TICHỲ 2002, TICHỲ and HOLT 2006, TICHỲ et al. 2010).

Species richness and species diversity

The distinguished plant communities were compared in relation to species richness and species diversity. For these purpose, for each community the mean number of species (no.) and mean value of Shannon-Wiener diversity index (*H'*) were calculated in JUICE 7.0 program taking into account abundance of species (TICHỲ and HOLT 2006).

Flood risk assessment

Area threatened by flooding was based on the range of the previous floods that have taken place since the beginning of the 20th century. Available historical data, photographic documentation, expertises and flood risk maps were used (RZĘTAŁA 2000, ABSALON et al. 2001, ABSALON et al. 2007, SCHMIDT 2009, ZAWARTKA 2012, *Centrum Ratownictwa Gliwice* 2015, Krajowy Zarząd Gospodarki Wodnej 2015).

Questionnaire survey

In June 2017 a direct questionnaire survey was conducted on the actual state of the Kłodnica valley in Gliwice and the necessity of its revitalization, as well as on ecological awareness of the inhabitants and their perception of ecosystem services provided by the river. The research population was 100 residents of Gliwice, including students living in a student dormitories and rented flats. The data was collected on socio-demographical attributes of interviewers related to their gender, age, level of education, current status of work and place of residence (district). At the beginning of the survey, the respondents were informed in details about its purpose. The structure of survey and the way of answering particular questions were also briefly explained. Respondents were asked 11 questions. There were 6 open questions and 5 closed questions.

Results

Classification of current vegetation of the Kłodnica valley

The classification of the vegetation based only on the floristic criterion enabled 23 plant communities to be distinguished. They contained from 2 to 18 phytosociological relevés. Along the semi-natural section of the Kłodnica valley 18 plant communities constituted by 139 vascular plant species were recorded. In contrast, along the anthropogenic section 13 plant communities created by 86 species were identified. 10 plant communities occurred only in the semi-natural section, 5 communities – exclusively in the anthropogenic section, and 8 communities were common to both studied sections of the Kłodnica valley. The descriptions of plant communities was given below (Table 1).

Table 1

Diagnostic (Dg), constant (C) and dominant (Dm) species for the plant communities that were distinguished.

Plant communities	Research section	Diagnostic, constant and dominant species
U-A	SA	Dg: *Aegopodium podagraria* (41.9), *Ballota nigra* (31.2); C: *A. podagraria* (85), *Urtica dioica* (42); Dm: *A. podagraria* (100)
U-C	SA	Dg: *Urtica dioica* (28.0), *Galium aparine* (20.1); C: *U. dioica* (78), *G. aparine* (43); Dm: *U. dioica* (89)
Sc	*A*	Dg: *Solidago canadensis* (54.7), *Humulus lupulus* (30.0); C: *S. canadensis* (85); Dm: *S. canadensis* (100), *H. lupulus* (33), *Aegopodium podagraria* (33)
Ip-Gp	*A*	Dg: *Impatiens parviflora* (66.2), *Galeopsis pubescens* (34.8); C: *I. parviflora* (63); Dm: *I. parviflora* (60), *G. pubescens* (40)
G-Ch	SA	Dg: *Chelidonium majus* (63.6), *Geum urbanum* (25.8); C: *C. majus* (84); Dm: *C. majus* (100)
Ap-Vs	*S*	Dg: *Alliaria petiolata* (54.4), *Valeriana sambucifolia* (27.2); C: *A. petiolata* (81), *Urtica dioica* (43); Dm: *A. petiolata* (100)
Ig	*S*	Dg: *Impatiens glandulifera* (45.4), *Veronica chamaedrys* (28.0), *Equisetum palustre* (25.7), *Myosotis palustris* (23.4), *Rubus idaeus* (21.5); C: *I. glandulifera* (47); Dm: *I. glandulifera* (50), *Anthriscus sylvestris* (50)
Ap	*S*	Dg: *Alopecurus pratensis* (83.0), *Ranunculus repens* (24.0), *Cirsium arvense* (23.3), *Holcus lanatus* (23.0); C: *A. pratensis* (82); Dm: *A. pratensis* (100)
Phr	SA	Dg: *Phragmites australis* (66.7); C: *P. australis* (84); Dm: *P. australis* (100)

Sg	SA	Dg: *Solidago gigantea* (45.8); C: *S. gigantea* (86); Dm: *S. gigantea* (100)
Bi	A	Dg: *Bromus inermis* (58.3); C: *B. inermis* (88); Dm: *B. inermis* (100)
Ae	SA	Dg: –; C: *Arrhenatherum elatius* (67); Dm: *A. elatius* (50), *Eupatorium cannabinum* (50)
Hm	*S*	Dg: *Heracleum mantegazzianum* (84.2); C: *H. mantegazzianum* (85); Dm: *H. mantegazzianum* (100), *Scrophularia nodosa* (50)
Rj	SA	Dg: *Reynoutria japonica* (95.2), *Convolvulus arvensis* (22.3), *Calystegia sepium* (21.7); C: *R. japonica* (96); Dm: *R. japonica* (100)
Ht	*A*	Dg: *Helianthus tuberosus* (79.6), *Chenopodium album* (36.6), *Leontodon hispidus* (36.6), *Plantago media* (36.6), *Agropyron repens* (34.9); C: *H. tuberosus* (72), *A. repens* (47); Dm: *H. tuberosus* (75), *A. repens* (25)
Anb-Pi	A	Dg: *Aster novi-belgii* (76.1), *Parthenocissus inserta* (57.3), *Rubus caesius* (32.2); C: *A. novi-belgii* (73), *R. caesius* (49), *P. inserta* (43); Dm: *A. novi-belgii* (80), *P. inserta* (40)
Ce	SA An	Dg: *Calamagrostis epigejos* (60.0); C: *C. epigejos* (82); Dm: *C. epigejos* (100)
Dc	*S*	Dg: *Deschampsia caespitosa* (75.5); C: *D. caespitosa* (81); Dm: *D. caespitosa* (100)
Fr	*S*	Dg: *Festuca rubra* (56.8), *Rumex acetosa* (47.4), *Viola tricolor* (43.9), *Cardaminopsis halleri* (32.3), *Luzula campestris* (29.4), *Achillea millefolium* (23.7), *Ranunculus acris* (21.1), *Galium mollugo* (20.1); C: *F. rubra* (88); Dm: *F. rubra* (100)
Ss	*S*	Dg: *Scirpus sylvaticus* (56.3); C: *S. sylvaticus* (84); Dm: *S. sylvaticus* (100)
Phal	*S*	Dg: *Phalaris arundinacea* (64.6); C: *P. arundinacea* (90); Dm: *P. arundinacea* (100)
Ip-Gm	*S*	Dg: *Iris pseudacorus* (71.9), *Glyceria maxima* (69.3), *Caltha palustris* (37.7), *Lotus uliginosus* (25.3), *Juncus effusus* (20.3); C: *I. pseudacorus* (61), *G. maxima* (52); Dm: *I. pseudacorus* (57), *G. maxima* (43)
Lm	*S*	Dg: *Lemna minor* (85.0), *Lemna trisulca* (53.6); C: *L. minor* (82); Dm: *L. minor* (85)

Explanations: research section: *S* – semi-natural, *A* – anthropogenic; abbreviations of the names of plant communities means: (U-A) *Urtico-Aegopodietum podagrariae*, (U-C) *Urtico-Calystegietum sepium*, (Sc) *Solidago canadensis*, (Ip-Gp) *Impatiens parviflora-Galeopsis pubescens*, (G-Ch) *Geo urbani-Chelidonietum maji*, (Ap-Vs) *Alliaria petiolata-Valeriana sambucifolia*, (Ig) *Impatiens glandulifera*, (Ap) *Alopecurus pratensis*, (Phr) *Phragmitetum australis*, (Sg) *Solidago gigantea*, (Bi) *Bromus inermis*, (Ae) *Arrhenatheretum elatioris*, (Hm) *Heracleum mantegazzianum*, (Rj) *Reynoutria japonica*, (Ht) *Helianthus tuberosus*, (Anb-Pi) *Aster novi-belgii-Parthenocissus inserta*, (Ce) *Calamagrostis epigejos*, (Dc) *Deschampsia caespitosa*, (Fr) *Festuca rubra*, (Ss) *Scirpetum sylvatici*, (Phal) *Phalaridetum arundinaceae*, (Ip-Gm) *Iris pseudacorus-Glyceria maxima*, (Lm) *Lemnetum minoris*.

1. *Urtico-Aegopodietum podagrariae*: medium-sized patches (50 m^2) of nitrophilous fringe community with *Aegopodium podagraria* or *Ballota nigra* were recorded in shady, slightly inclined (0–20°) places, as well as at the top and in the middle part of the slopes of the semi-natural and anthropogenic section of the Kłodnica valley. The average height of the herb layer is 105 cm.

2. *Urtico-Calystegietum sepium*: medium-sized patches (50 m^2) nitrophilous “weil” community with *Urtica dioica* and *Galium aparine* occur on flat or slightly inclined slopes (0–20°), shaded places, at the top and in the middle part of the embankments of the semi-natural and anthropogenic section of the Kłodnica valley. The average height of the herb layer is 142 cm.

3. *Solidago canadensis* community: small-sized (30 m^2) patches dominated by *Solidago canadensis* and *Humulus lupulus* were recorded on open sites on slightly inclined (0–15°) embankments of anthropogenic section of the Kłodnica valley. The average height of the herb layer is 140 cm.

4. *Impatiens parviflora-Galeopsis pubescens* community: large patches (125 m^2) of the nitrophilous fringe community with *Impatiens parviflora* and *Galeopsis pubescens* were developed under the canopy of trees, in depressions and in the flattening along the anthropogenic sections of the Kłodnica valley. The average height of the herb layer is 59 cm.

5. *Geo urbani-Chelidonietum maji*: small-sized patches (25 m^2) of nitrophilous fringe community with *Chelidonium majus* and *Geum urbanum* occur on shaded and flat sites along the semi-natural and anthropogenic section of the Kłodnica valley. The average height of the herb layer is 45 cm.

6. *Alliaria petiolata-Valeriana sambucifolia* community: medium-sized (96 m^2) patches of the *Alliaria petiolata* and *Valeriana sambucifolia* nitrophilous fringe community were recorded under the canopy of trees, at the top and in the middle part of embankments of the semi-natural section of the Kłodnica valley on a 0–20° slope inclined. The average height of the herb layer is 120 cm.

7. *Impatiens glandulifera* community: small-sized (40 m^2) patches with a dominance of *Impatiens glandulifera* occurs in slightly inclined ($0–15^0$) shaded sites, at the top and in the middle part of the waterside of the semi-natural section of the Kłodnica valley. The average height of the herb layer is 130 cm.

8. *Alopecuretum pratensis*: large patches (130 m^2) of the meadow community with such diagnostic species as *Alopecurus pratensis*, *Ranunculus repens*, *Cirsium arvense* and *Holcus lanatus* developed on open and waterlogged sites on the floodplain terrace of the semi-natural section of the Kłodnica valley. The average height of the herb layer is 126 cm.

9. *Phragmitetum australis*: small in size (25 m^2) patches of a rush community with *Phragmites australis* were recorded on floodplain terrace of the semi-natural section of the Kłodnica valley, as well as nearby the riverbed of the anthropogenic section of the Kłodnica valley. The average height of the herb layer is 160 cm.

10. *Solidago gigantea* community: an aggregation of *Solidago gigantea*, the average height of the herb layer is 164 cm. Compact, large-sized (150 m^2) patches of the community occur on open places with inclination of 0–20° on the riverside of the semi-natural and anthropogenic section of the Kłodnica valley.

11. *Bromus inermis* community: a ruderal community with a dominance of *Bromus inermis*, the average height of the herb layer is 127 cm. Medium-sized (90 m^2) patches of the community developed at the top and in the middle part of the embankments of the anthropogenic section of the Kłodnica valley, slopes inclined at an angle 2–20°.

12. *Arrhenatheretum elatioris*: small in size (15 m^2) patches of a fresh meadow with a dominance of *Arrhenatherum elatius* were recorded at the top of embankments of semi-natural and anthropogenic section of the Kłodnica valley, slightly inclined 5–20°. The average height of the herb layer is 115 cm.

13. *Heracleum mantegazzianum* community: the height of the herb layer is up to 400 cm. Small (15 m^2) patches of the community were noted in shaded and slightly sloped (5°) sites, nearby the riverbed along the semi-natural section of the Kłodnica valley.

14. *Reynoutria japonica* community: compact large-sized (105 m^2) aggregations of invasive species *Reynoutria japonica* phytocoenoses occur on open places on the floodplain terrace of the semi-natural section of the Kłodnica valley, as well as along the pathways and at the top of embankments of the anthropogenic section of the Kłodnica valley with a slope 0–15°. The average height of the herb layer is 260 cm.

15. *Helianthus tuberosus* community: small (25 m^2) patches of the *Helianthus tuberosus* community were recorded on flat sites along the anthropogenic section of the Kłodnica valley. The average height of the herb layer is 193 cm

16. *Aster novi-belgii-Parthenocisus inserta* community: large-sized (300 m^2) patches of *Aster novi-belgii*, *Parthenocissus inserta* and *Rubus caesius* phytocoenoses developed along embankments of the anthropogenic section of the Kłodnica valley, in open sites with a slope 5–15°. The average height of the herb layer is 110 cm.

17. *Calamagrostis epigejos* community: patches of this grassy community occupy large areas (120 m^2) on the floodplain terrace of semi-natural section of the Kłodnica valley, as well as at the top of riverside of the anthropogenic section of the Kłodnica valley with a slope 10–15°. The average height of the herb layer is 152 cm.

18. *Deschampsia caespitosa* community: large patches (110 m^2) of this wet meadow community were recorded in open and often heavily moiste-

ned sites on the floodplain terrace of the semi-natural section of the Kłodnica valley. The average height of the herb layer 45 cm.

19. *Festuca rubra* community: large patches (200 m^2) of dry meadow phytocoenoses occur in open places, on less moistened soils on the floodplain terrace of the semi-natural section of the Kłodnica valley. The average height of the herb layer is 50 cm.

20. *Scirpetum sylvatici*: small in size patches of this wet meadow community (30 m^2) were recorded in open and frequently moistened sites near the riverbed and depressions periodically filled with water on the floodplain terrace of the semi-natural section of the Kłodnica valley. The average height of the herb layer is 70 cm.

21. *Phalaridetum arundinaceae*: medium-sized rush community (62 m^2) developed in water depressions, as well as in wet sites on the floodplain terrace of the semi-natural section of the Kłodnica valley. The average height of the herb layer is 168 cm.

22. *Iris pseudacorus*-*Glyceria maxima* community: medium-sized (52 m^2) patches of the rush community were recorded in depressions filled with water and shaded by trees on the semi-natural section of the Kłodnica valley. The average height of the herb layer is 130 cm.

23. *Lemnetum minoris*: large-sized (100 m^2) patches of aquatic community with *Lemna minor* and *L. trisulca* phytocoenoses developed on the surface of water that filled local depressions in the area of the semi-natural section of the Kłodnica valley.

Species richness and species diversity

Plant communities recorded along the semi-natural section of the Kłodnica valley were richer in species and more diverse than phytocoenoses that occurred along anthropogenic section. The exception are aggregative patches of aquatic community – *Lemnetum minoris*, created only by 2 species – *Lemna minor* and *L. trisulca* (Figure 2 and Figure 3).

Along the semi-natural section of the Kłodnica valley developed the species-rich and diverse communities of wet (*Alopecuretum pratensis*: no. = 18.25, H' = 2.15) and fresh (*Festuca rubra* community: no. = 14.33, H' = 1.87) meadows, as well as phytocoenoses of nitrophilous fringe communities (*Urtico-Calystegietum sepium*: no. = 15.20, H' = 2.04; *Alliaria petiolata*-*Valeriana sambucifolia* community: no. = 14.86, H' = 1.92). It is worth paying attention, that the most rich in species (no. = 19.50) and the most diverse (H' = 2.25) was community built by an invasive species – *Impatiens glandulifera*. However, it is a community with the physiognomy of the nitrophilous fringe, in which encroaching of *Impatiens glandulifera*

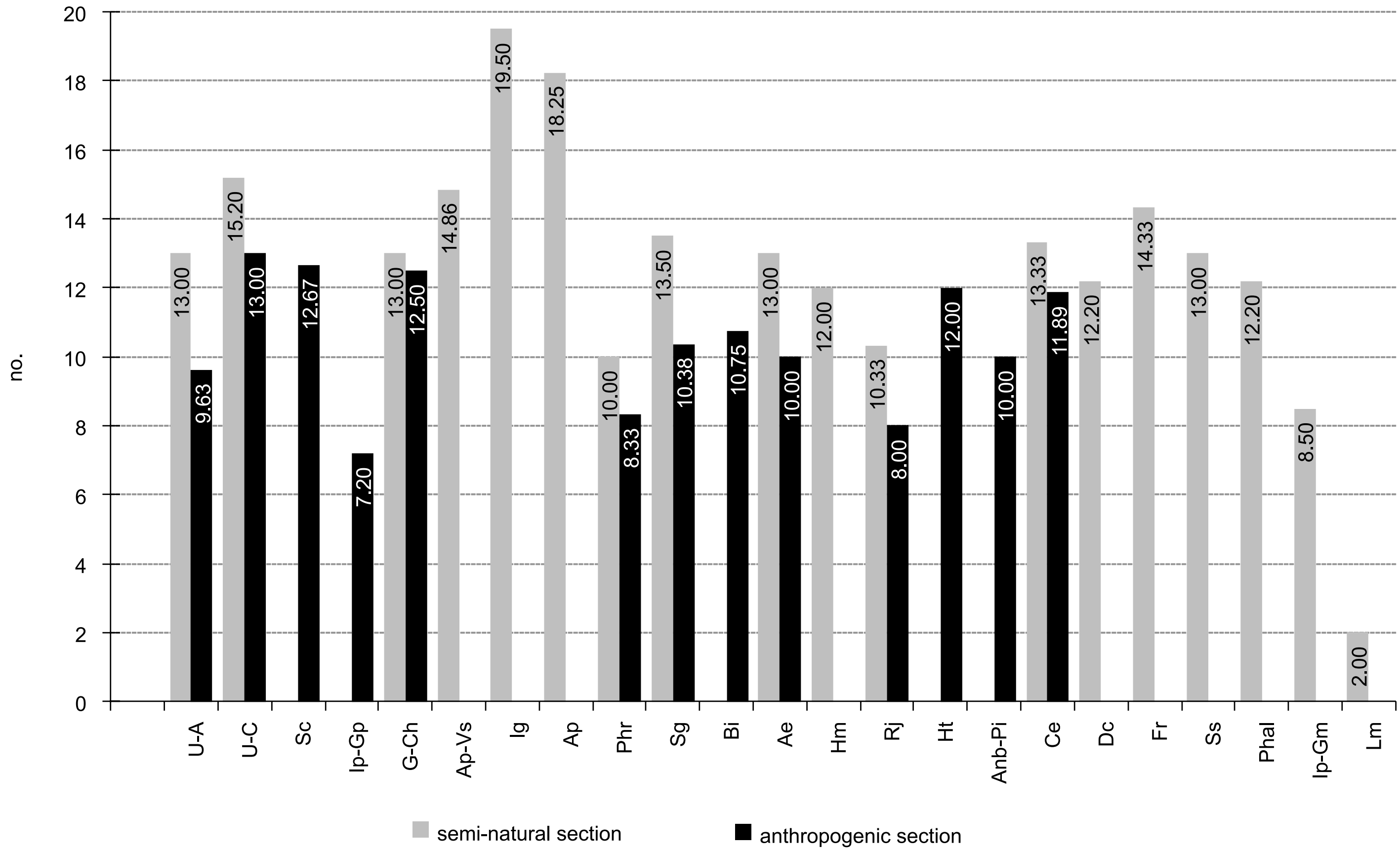

Fig. 2. Comparison species richness of the vegetation of two section of the Kłodnica valley being under different levels of anthropogenic transformations

Explanations: no. – means the average number of species. See Table 1 for explanations of the abbreviations for the names of the plant communities

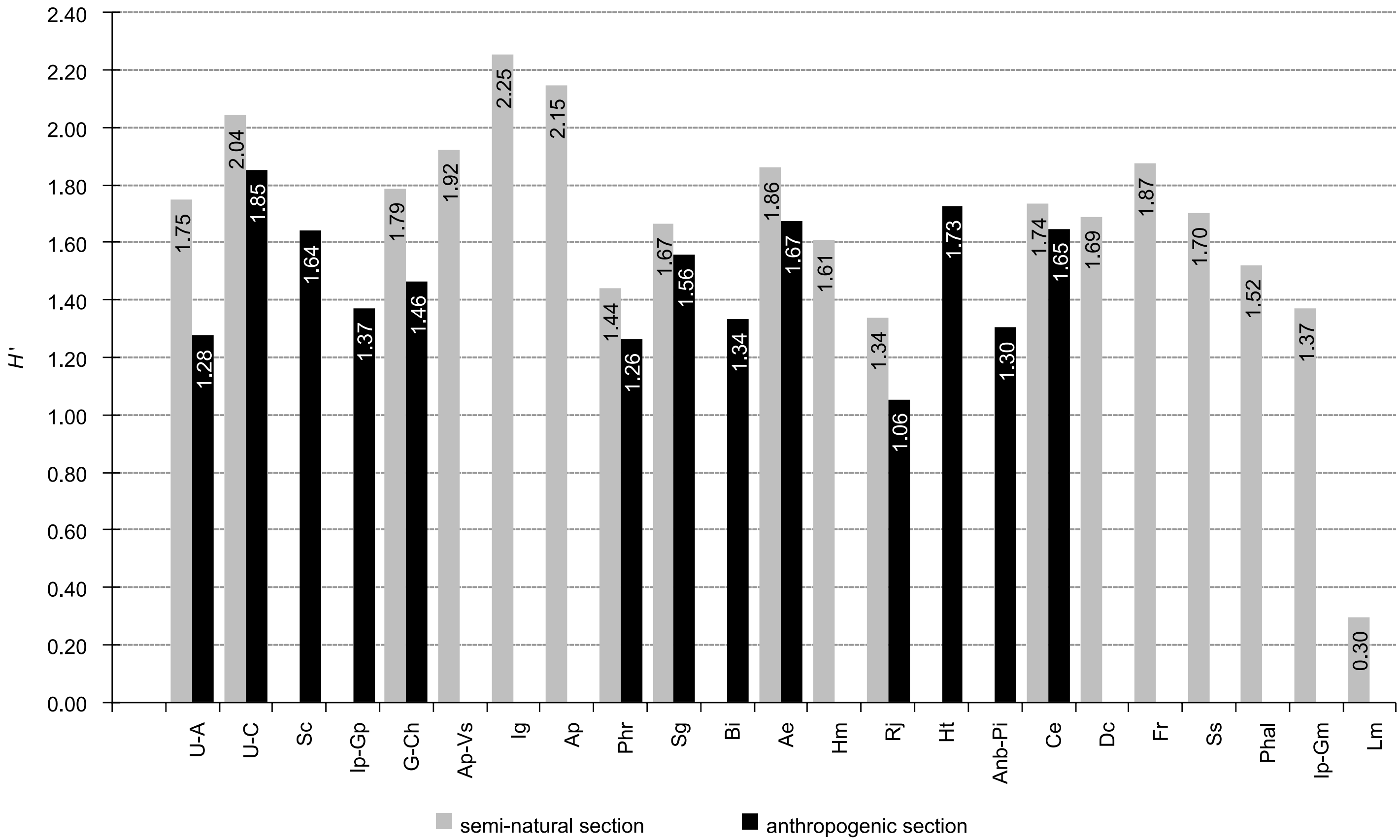

Fig. 3. Comparison of species diversity of the vegetation of two section of the Kłodnica valley being under different levels of anthropogenic transformations

H' – the average value of Shannon-Wiener diversity index. See Table 1 for explanations of the abbreviations for the names of the plant communities is observed. In the species composition of those phytocoenoses occur nitrophilous (*Anthriscus sylvestris*, *Rubus idaeus*) and meadow (*Veronica chamaedrys*, *Equisetum palustre*, *Myosotis palustris*) plants (Table 1, Figure 2 and Figure 3).

The poorest in species and the least diverse were aggregation of invasive species – *Impatiens parviflora* (no. = 7.20, *H'* = 1.37), *Reynoutria japonica* (no. = 8.00, *H'* = 1.06), *Aster novi-belgii* and *Parthenocissus inserta* (no. = 10.00, *H'* = 1.30), as well as *Urtico-Aegopodietum podagrariae* phytocoenoses (no. = 9.63, *H'* = 1.28) and grass-like community with *Bromus inermis* (no. = 10.75, *H'* = 1.34), which recorded through the anthropogenic section of the Kłodnica valley. Lower number of species and lower diversity were also characterized rushes with dominance of expansive grass, such as *Phragmitetum australis* (semi-natural section: no. = 10.00, *H'* = 1.44; anthropogenic section: no. = 8.33, *H'* = 1.26) and community with *Iris pseudacorus* and *Glyceria maxima* (no. = 8.50, *H'* = 1.37) – Figure 2 and Figure 3.

Flood risk assessment

For the area of Panewniki (Katowice district), where the semi-natural research section is located, there is no information about flood events. On the basis of data presented on the maps of flood risks by the National Water Management it can be detected, that along the semi-natural section of the Kłodnica valley the probability of flood occurrence is low and amounts to once a 500 years (Q 0.2%), and the flood risk area is limited to green fields in the immediate vicinity of the riverbed – Figure 4.

In contrast, in the anthropogenic section, 10 flood events have been recorded since the beginning of regular observation of the water level in Gliwice in 1911. The floods took place in 1913, 1915, 1925, 1930, 1940, 1970, 1972, 1985, 1997 and 2010. The largest flood took part at the turn May and June 1940. The water level in Kłodnica was 505 cm, and the flow was 121.5 $m^3 s^{-1}$. For comparison, in July 1997 the water level was 360 cm and flow rate 88.1 $m^3 s^{-1}$, while during the last flood in May 2010 water level was 384 cm and flow 105 $m^3 s^{-1}$ (Figure 5). The frequency of floods in the last 108 years makes it possible to predict, that the probability of flood occurrence is high and amounts to once a 10 years (Q 10%). The area at risk of flooding in Sośnica, Baildon, Ligota Zabrska and Politechnika (Gliwice districts) is 1.8 km^2 at the height of flood wave $\geq$ 350 cm. When the level of flood wave reaches $\geq$ 505 cm, Śródmieście is also at risk of flooding, and the flood risk area is 2.1 km^2. Within the area of above-mentioned districts threatened by flooding, apart from dense residential and industrial

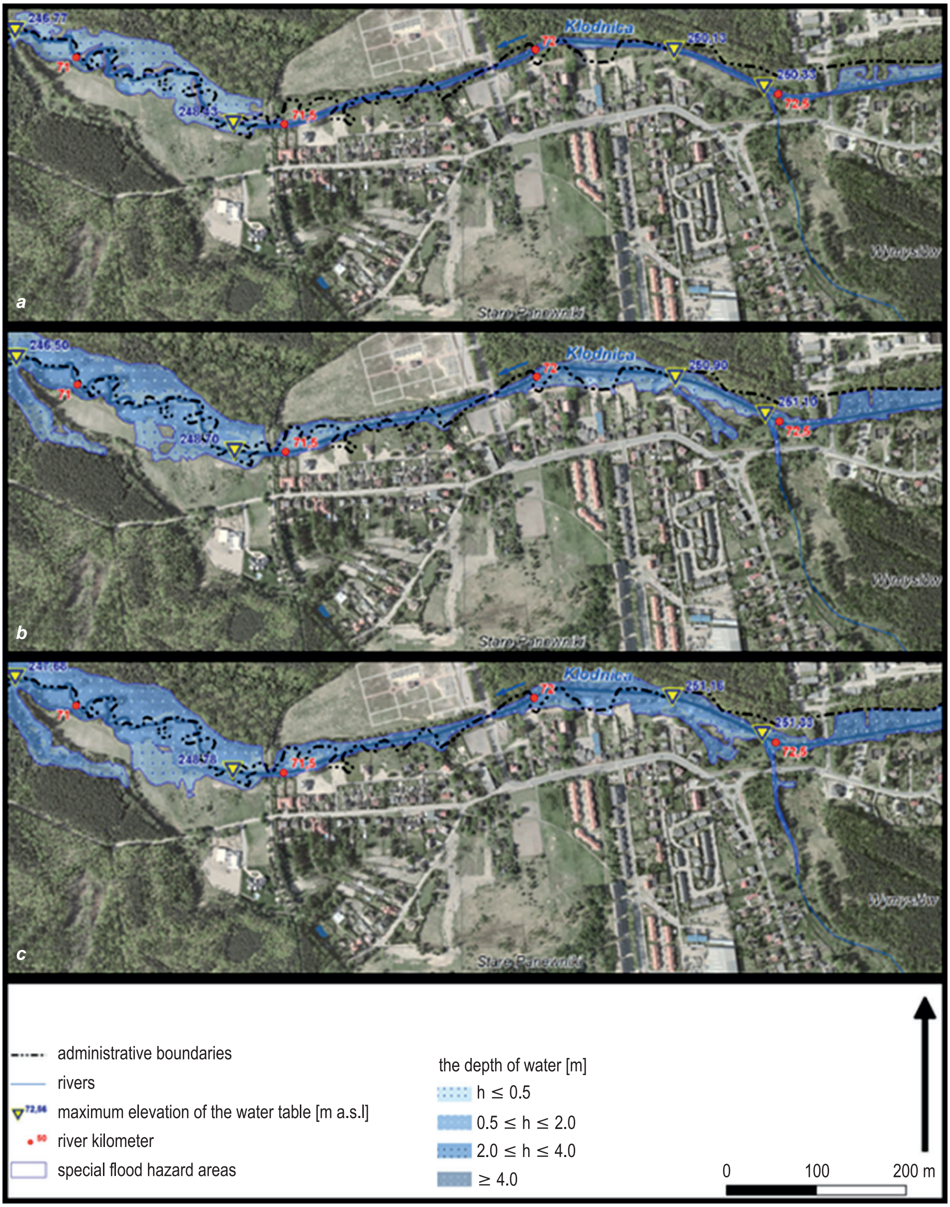

Fig. 4. Flood risk map of Katowice-Panewniki (semi-natural section):
a – areas, in which the probability of flood occurrence is low and amounts to once a 500 years (Q 0.2%); *b* – areas, in which the probability of flood occurrence is medium and amounts to once a 100 years (1%); *c* – areas, in which the probability of flood occurrence is high and amounts to once a 10 years (Q 10%)

Source: Krajowy Zarząd Gospodarki Wodnej (2015)

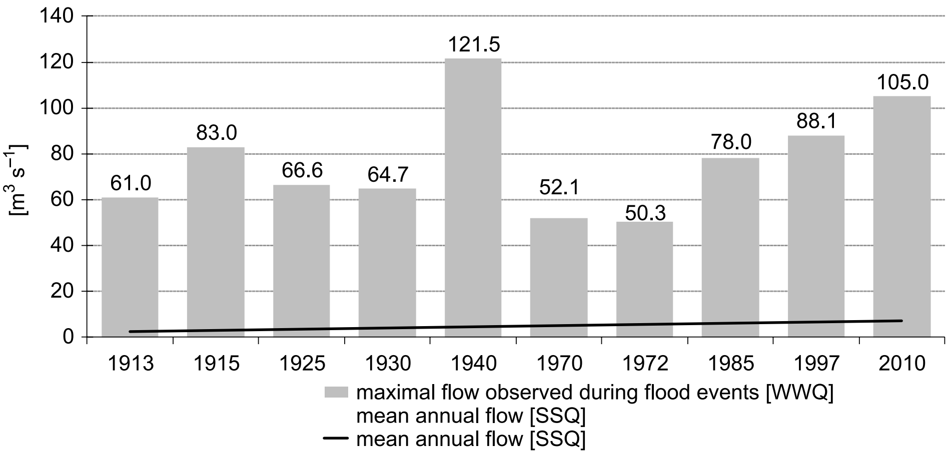

Fig. 5. Maximal flows (WWQ) observed during flood events in a period 1913–2010 in Gliwice (anthropogenic section)

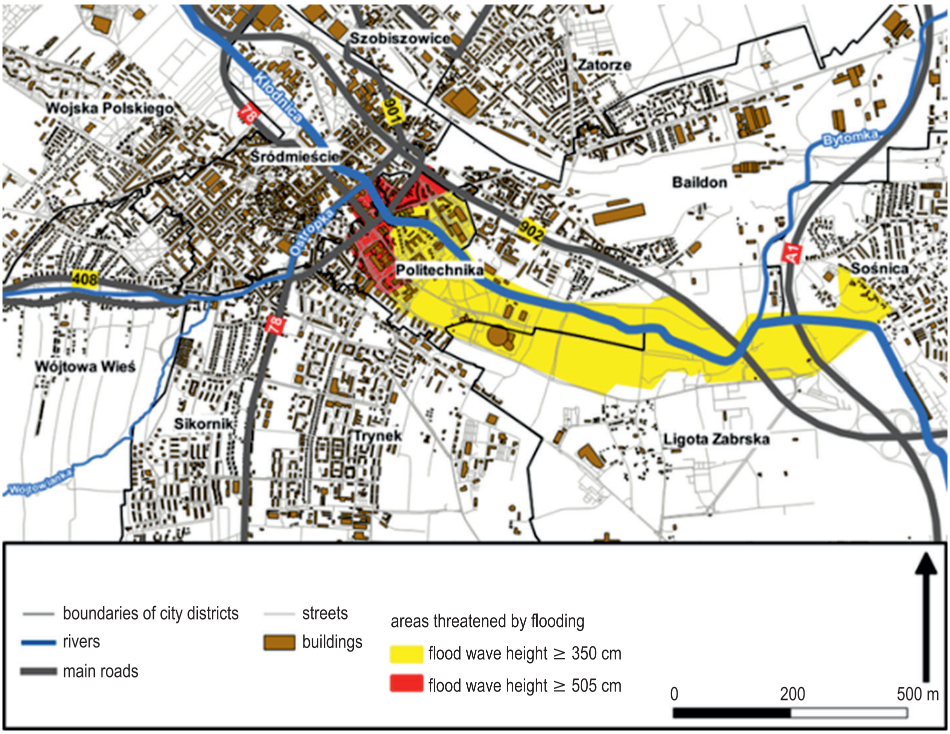

Fig. 6. Flood risk map of Gliwice (anthropogenic section)

buildings and road networks, there are also important facilities, such as the Chrobry city park, large Entertainment-Sports Hall „Gliwice", faculties of the Silesian University of Technology, Science and Technology Park

"Technopark Gliwice", primary and secondary schools, the Municipal Headquarters of the State Fire Service and the County Sanitary-Epidemiological Station (Figure 6).

Questionnaire survey

In the group of 100 respondents, 58% were females and 42% were males. The age structure was dominated by respondents in the age group from 20 to 25 years (23%). They were followed by respondents aged 26–39 (19%), 16–19 (18%), 40–60 (16%), 6–15 (14%) and above 60 years (10%) respectively. The largest number of respondents were those with primary education (23%), basic vocational education (22%) and higher education (22%). The share of the upper (19%) and lower (14%) secondary school leavers was lower. Taking into account the current labour status employed (37%) and pupils (32%) prevailed over students (16%), retired (11%) and unemployed (4%). The vast majority (76%) of respondents lived in districts threatened by flooding, while 24% lived in other districts of the city of Gliwice.

The majority of the respondents visited the Kłodnica valley daily (40%) or 1–3 times a week (31%). Interviewees indicated walking with the dog (28%), walking (25%), jogging/running (12%) and playing with children (9%) as the purpose of the visit. Respondents generally rated the landscape of the Kłodnica valley, as monotonous (39%) and disturbed (33%). Positive connotations with the valley, such as wild (16%), diverse (7%) and near-natural (5%) were generally less frequent (Figure 7).

The interviewees rated the valley landscape (83%), river water quality (100%), plant cover (78%) and infrastructure (77%) as unattractive or rather unattractive. Cultural and historical values assessed as attractive or rather attractive (51%). In the case of tourist values of the Kłodnica valley, the share of positive (attractive or rather attractive, 46%), as well as negative opinions (unattractive or rather unattractive, 46%) was similar (Figure 8). Almost half of the respondents (46%) were not able to show elements increasing the attractiveness of the Kłodnica valley. Others interviewees appreciated the advantages of the Kłodnica valley, such as "place for walking" (24%), "place for rest and recreation" (17%) and "green place near the city center" (13%). According to the respondents, the main features decreasing the attractiveness of the Kłodnica valley are often floods (39%), unpleasant smell (14%), pollution of the river (10%), monotonous vegetation (10%), lack of recreational infrastructure (9%) and riverbed regulation (6%). The majority of interviewees completely agree (51%) or mostly agree (25%) with the necessity of revitalization of the Kłodnica valley (Figure 9).

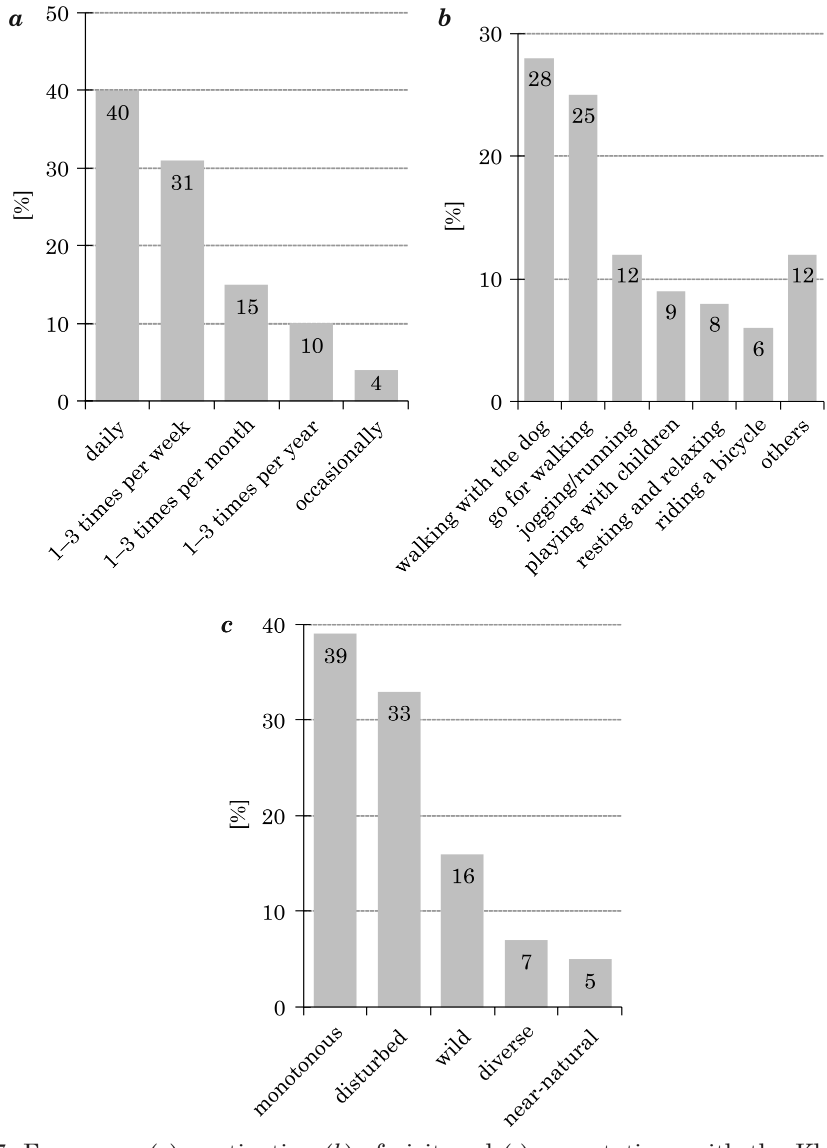

Fig. 7. Frequency (*a*), motivation (*b*) of visit and (*c*) connotations with the Kłodnica valley in Gliwice (anthropogenic section)

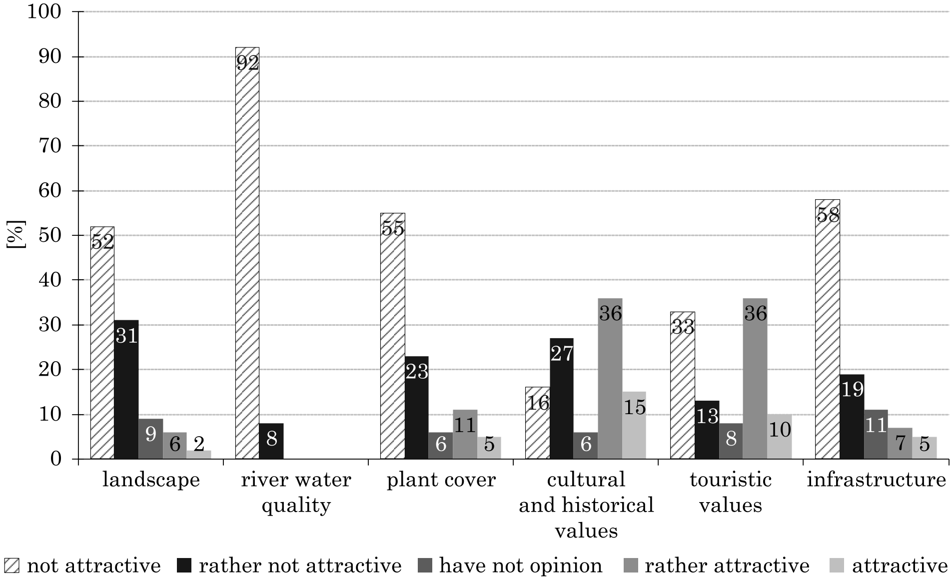

Fig. 8. Evaluation of the attractiveness of the Kłodnica valley in Gliwice (anthropogenic section)

More than half (58–95%) of the respondents could recognize 8 out of 11 plant species, that occur abundantly in the Kłodnica valley (Figure 10). Only 28% of the interviewees correctly found out, which of the presented plants were native species in comparison with the invasive ones. 26% of the respondents did not know the negative effects caused by invasive species. Others interviewees most often mentioned monotypization of vegetation (22%) and the decrease in the attractiveness of the landscape (17%). Only few respondents mentioned such effects as loss of the biodiversity (14%), displacement of native species by alien ones (10%), disturbances in ecosystem functioning (7%) and economic losses (4%). The concept of ecosystem services was known only to 7% of respondents (Figure 11).

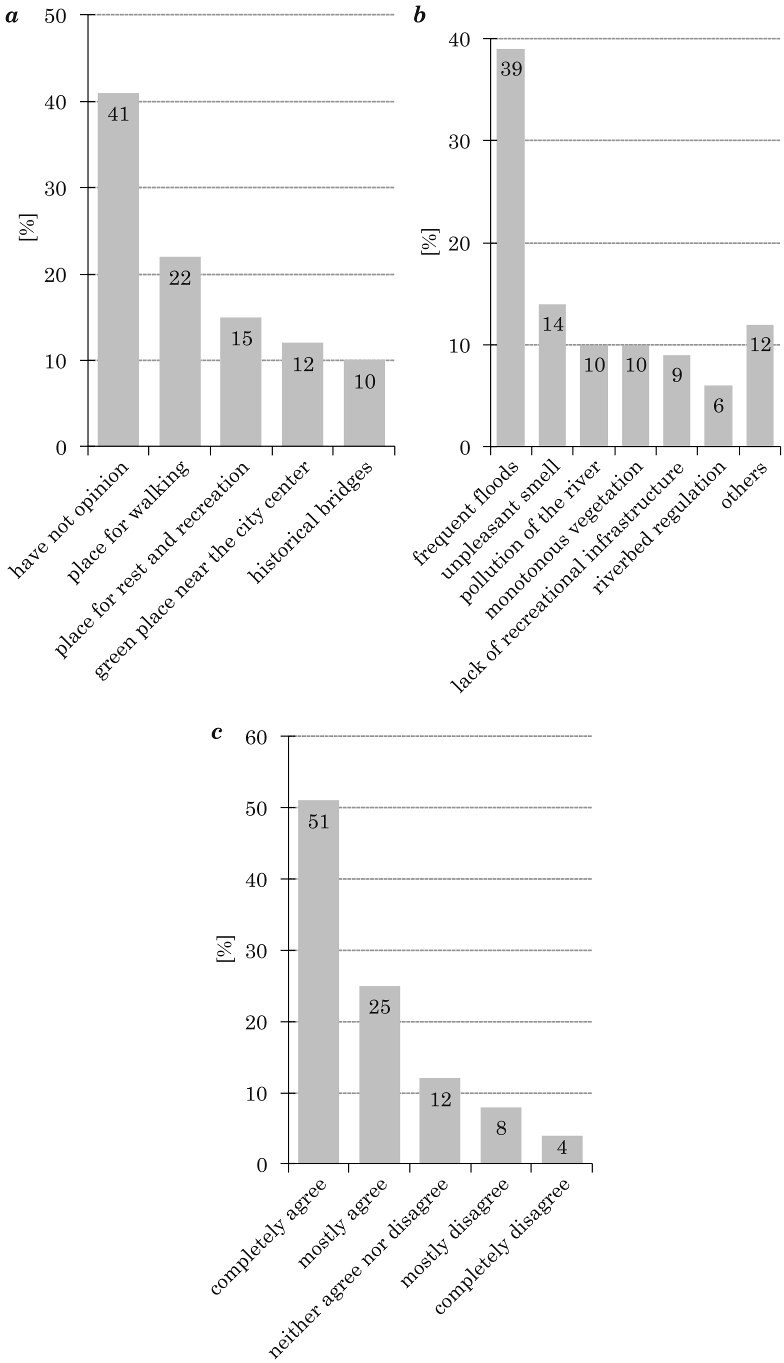

Fig. 9. Features increasing (*a*) and decreasing (*b*) the attractiveness of the Kłodnica valley in Gliwice (anthropogenic section). The necessity of revitalization of the valley (*c*)

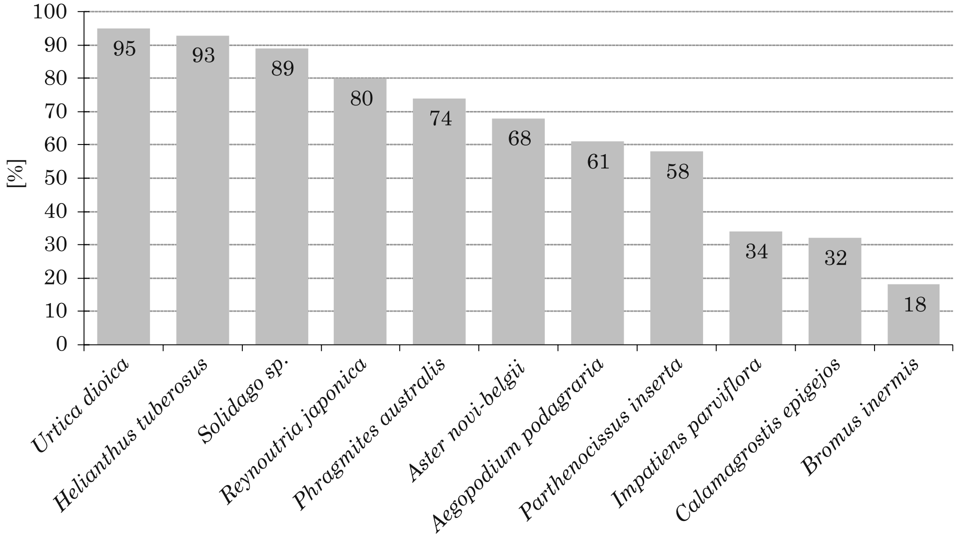

Fig. 10. Knowledge about plant species occurring abundantly in the Kłodnica valley in Gliwice (anthropogenic section)

Discussion

The vegetation of the semi-natural section of the Kłodnica valley in Katowice was represented by 18 plant communities and 139 vascular plants species, mainly of native origin. In comparison to other Polish river valleys, the vegetation cover of semi-natural section of the Kłodnica valley is characterized by moderate diversity. In the Zgłowiączka valley near the village of Janiszewo and Zgłowiączka in the Kuyavian-Pomeranian Voivodeship 76 phytocoenoses, built by 324 plant species were distinguished (WAROT et al. 2001). ŁASKA (2009) found 8 plant communities, created by 172 plant taxa in the Płoska valley near Supraśl in the Podlaskie Voivodship. GAMRAT et al. (2010) recorded 15 phytocoenoses and 102 plant species in Ina valley near Sowno in West Pomeranian Voivodeship. KRYSZAK and KRYSZAK (2010) identified 6 plant communities and 115 taxa of vascular plants in Główna valley in the vicinity of Wierzenica in Greater Poland Voivodeship. Rich in species and diversified phytocoenoses of wet and fresh meadow, as well as nitrophilous fringe communities developed along the semi-natural section of the Kłodnica valley. The highest number of species and species diversity characterized *Impatiens glandulifera* community. Results of studies devoted to the impact of *Impatiens glandulifera* on diversity of vegetation are contradictory (TOKARSKA-GUZIK et. al 2015).

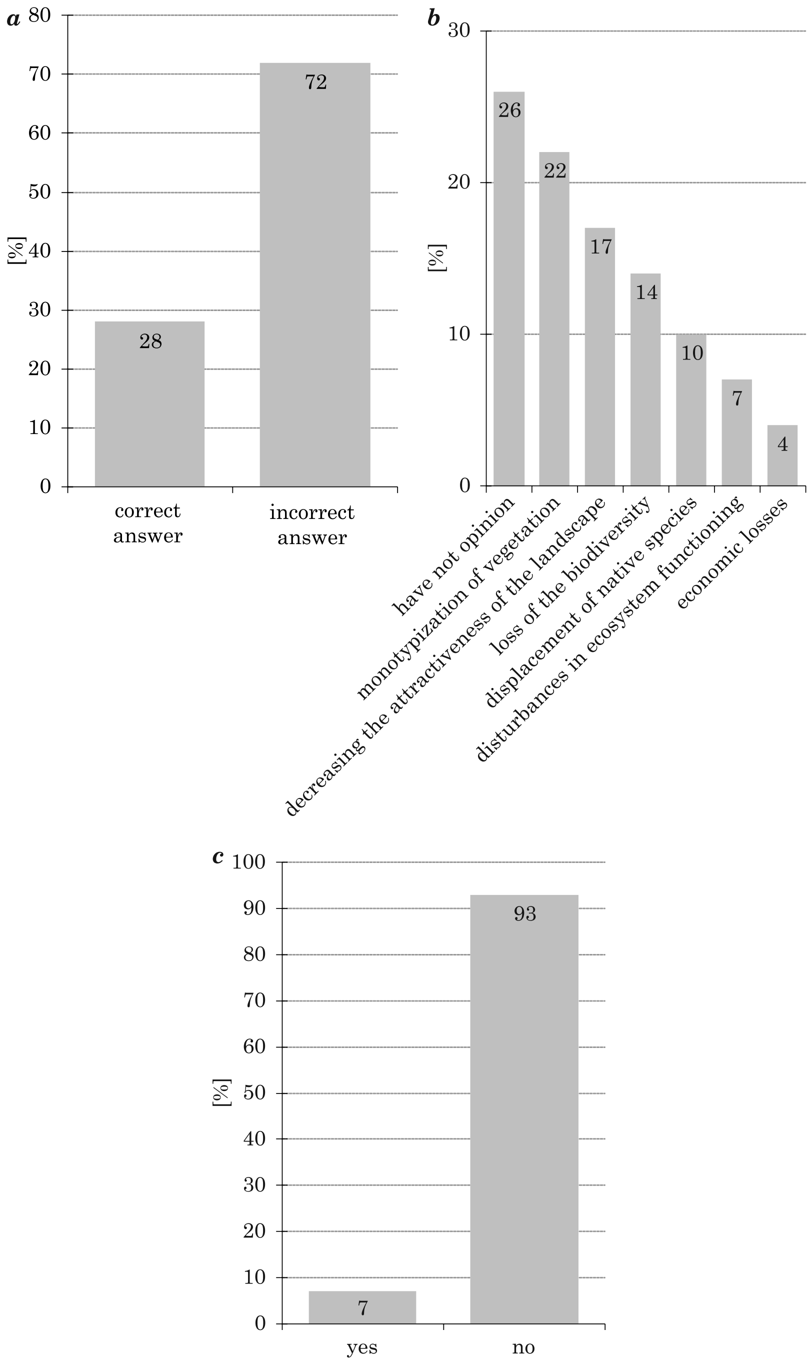

Fig. 11. Recognition of native and invasive plant (*a*), knowledge of the effects caused by invasive species (*b*) and the concept of ecosystem services (*c*)

On the one hand, in the initial stage of invasion it is possible, that species richness and species diversity of invaded vegetation increased, whereas in later stages of invasion decreased (HULME and BREMMER 2005, JAROSZEWICZ 2011). According to HEJDA and PYŠEK (2006), the impact of *Impatiens glandulifera* may depend on the density of the population. In our case *Impatiens glandulifera* does not occur abundantly. This plant community is co-created mainly by nitrophilous and meadow species. Low degree of anthropogenic disturbances of vegetation caused the semi-natural section of the Kłodnica valley is a place of a high natural and landscape value (MATUSIAK and WOJTCZAK 2006). A well-developed plant cover is also important in reducing of flood risk, which has been indicated along the semi-natural section of the Kłodnica valley as low. Vegetation plays an important role in rainwater retention and limits the surface runoff. In the period of elevated water levels in the river, the valley which is almost 100 m in width, densely overgrown by permanent grassland serves as a "dry polder". Period water retention enables to reduce the flow rate and effectively cut off the flood wave (BEDNARCZYK et al. 2006, JANKOWSKA-HUFLEJT 2006, JANUCHTA-SZOSTAK 2012, 2017, Krajowy Zarząd Gospodarki Wodnej 2015, MIODUSZEWSKI 2016, JANKOWSKI 2017, PRUS et al. 2018).

The contemporary landscape of the anthropogenic section of the Kłodnica valley has been created as a result of over 200 years of human economic activity (ABSALON et al. 2007). Willow shrubs (*Salicetum triandro-viminalis*) and willow-poplar forests (*Salicetum albo-fragilis*, *Populetum albae*), which naturally occurred in the valley, were cut down during regulatory works, including the riverbed straightening and the construction of embankments (HANCZARUK et al. 2016). Kłodnica waters received significant amounts of municipal and domestic sewage, as well as salty groundwater from hard coal mines (BARBUSIŃSKI and NOCOŃ 2011). In the place of riparian vegetation, 13 secondary non-forest plant communities, created by 86 species of vascular plants were developed. Among them were poor in species and low diverse aggregations of invasive alien plants (*Impatiens parviflora*, *Reynoutria japonica*, *Aster novi-belgii*, *Parthenocissus inserta*) and phytocoenoses with dominance of expansive species (*Aegopodietum podagraria*, *Bromus inermis*) have a negative influence on the landscape values of the valley. Strong modification of hydrogeological conditions, as well as destruction of the natural plant cover resulted in a twofold acceleration of the average annual flow (SSQ from 3.0 $m^3 s^{-1}$ before regulation to 6.41 $m^3 s^{-1}$ after regulation) and water damming of the river (RZĘTAŁA 2000, ABSALON et al. 2001, JANUCHTA-SZOSTAK 2012, ZAWARTKA 2012). Since 1911, 10 flood events have been recorded in the immediate vicinity of the anthropogenic section of the Kłodnica valley

(Absalon et al. 2007, Centrum Ratownictwa Gliwice 2015). The frequency of floods indicates, that the likelihood of floods is high. The spatial range of the previous floods allows to estimate, that over 2 km^2 of densely populated areas in the downtown districts of Gliwice is at risk of flooding (Absalon et al. 2007, Schmidt 2009, Centrum Ratownictwa Gliwice 2015). The losses caused by the last flood in municipal infrastructure in 2010 amounted to 13.1 million of PLN, and the costs associated with removing the floods amounted to 0.9 million PLN (Paliga and Knura 2013).

An questionnaire survey showed, that for the inhabitants of Gliwice, the Kłodnica valley is an important space for leisure and recreation needs. Similar conclusions were drawn by Bródka and Miedzińska (2015) for the Warta valley in Poznań, and Sender and Maslanko (2018) for Bystrzyca valley in Lublin. The majority of the respondents do not know the concept of invasive alien plants and ecosystem services. Therefore, it is important to undertake actions aimed at increasing the ecological awareness of local communities in the field of biodiversity, biological invasions, as well as the importance of riverside ecosystems and the value of ecosystem services provided by them. The usage of online social media (e.g. Facebook, Instagram, Twitter, Google+, etc.) will allow to transfer knowledge about the environment to a broader audience (Januchta-Szostak 2014, Pietrzak-Zawadka and Lewoń 2018). However, the majority of interviewees often visit the Kłodnica valley and perceive the anthropogenic disorders of the Kłodnica valley and their consequences. Most of them describe the Kłodnica valley as monotonous or disturbed and rated the valley landscape, water quality in the river, plant cover as unattractive or rather unattractive. Majority of respondents had a problem with showing the elements increasing the attractiveness of the Kłodnica valley. Similar results was obtained Bernat (2013) for the Bystrzyca valley in Lublin. Respondents often mentioned flood events, pollution of the river and associated with them unpleasant smell followed by monotonous vegetation and lack of recreational infrastructure as the main factors reducing attractiveness of the Kłodnica valley. Comparison with others Polish river valley shows, that high flood risk is the significant problem of the Kłodnica valley. The list of elements decreasing the attractiveness of the Bystrzyca valley in Lublin, includes water pollution and bad quality of water, and in the case of Warta valley in Poznań – pollution of water, insufficient care for the valley and lack of recreational infrastructure (Bródka and Miedzińska 2015, Sender and Maslanko 2018). As in other European cities, the inhabitants of Gliwice see the need for re-integration of the city with the river and indicate the necessity of revitalization of the Kłodnica valley (Szwed 2011).

Examples of other European cities (Duisburg, Oberhausen, Bottrop, Essen, Gelsenkirchen, Bochum, Dortmund and Bonn), where comprehensive revitalization projects of river valleys (e.g. Emscher Valley – one of the main river in Ruhr Area) have been implemented in recent years, providing valuable solutions and experience in various aspects of revitalization (WIERUSZEWSKI 1999, PANCEWICZ 2007, ZÖPEL 2011, BERNAT 2013, AUER and LAVIER 2013, LATKOWSKA 2014). In 2014 in Ostrava, the project "Revitalization of the Ostravice River" was launched. This includes the revitalization of riverbed, some plantings of riverbanks, the creation of a new cycle and walking paths and small architectural elements, the adaptation of the current pier for water sports, as well as the construction a workout area (LAMPARTOVÁ and SCHNEIDER 2014, PAJURKOVÁ 2017). The assumptions of the green infrastructure concept were successfully applied during the revitalization of the Ślepiotka valley (the western tributary of the Kłodnica river) in the Upper Silesia. Within the framework of the international project REURIS (Revitalization of Urban River Spaces) in the years 2010–2011, a 350-metre long section of Ślepiotka located along heavily urbanized areas of Ochojec (Katowice district) was revitalized. The cost of the project was 0.4 mln euro. Concrete riverbeds were replaced by natural material, such as boulders and wood. Invasive alien plant species were eliminated and natural habitat of river valley, as riparian and broadleaved forest and wetlands were restored. In addition, a wild flower meadow was created on an area of about 1 ha. The wooden amphitheatre at the entrance to the valley increases the cultural and landscape values of the Ślepiotka valley. The educational trail, as well as educational boards (riverine forests, species typical of forests, old varieties of fruit trees) arrange along it, contribute to building ecological awareness of the residents (*Śląski Związek...* 2011, BENDER et al. 2012, LANGE and NISSEN 2012, GIEROSZKA et al. 2014, JANISZEK 2015).

Revitalization of river valleys is a long-term and an multi-faced process, in which knowledge about ecosystem functioning, as well as existing socio-economic conditions should be applied (BERNAT 2013, GIEROSZKA et al. 2014). The objective should be to improve current state of the environment (reduction of solid, liquid and gaseous wastes flowing into rivers, restoration or reconstruction of vegetation in the coastal zone, improvement of abiotic conditions important for water biocenoses, as well as restoration of connections with other river valleys) (PRZEWOŹNIAK 2005). The final effect of properly carried out ecological revitalization should be the improvement of riverside ecosystems functioning and provision of many ecosystem services, such as decreasing the flood risk, improvement of local microclimatic conditions, as well as creation of friendly for inhabitants riverside spaces – places of rest, recreation and observation of nature (JANUCHTA-SZOSTAK 2012, LANGE and NISSEN 2012, JANISZEK 2015).

Conclusions

The field research carried out on the diversity of vegetation of the Kłodnica valley being under influence on long-lasting anthropopressure, as well as the results of studies on the perception of ecosystem services by the city residents indicate the need to continue and extend the field research to further sections (e.g. some streams flowing into Kłodnica, such as Bytomka, Ostropka, Wójtowianka) in terms of undertaken of revitalization activities of river valley, as well as to monitor the existing ecosystem services. The gain knowledge could enable to plan further investments in the river valley, which cannot contribute to the further weakening or even disappearance of some ecosystem services.

Research on the identification of ecosystem services would provide more complete data on the impairment of ecosystem services and enable to develop a better system of their evaluation.

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