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The pollution of surface water in the agricultural catchment against the background of agrarian structure and production intensity

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Abstract: The intensification of agricultural production is one of the factors determining economic development. Increasing mechanisation and use of fertilisers in agriculture lead to higher yields, but at the same time they can pose a threat to the environment. The overuse of chemical fertilisers contributes to increased concentration of nutrients in agricultural runoff. One of such areas is the Szreniawa River catchment, the study area located in the southern part of Poland. In this catchment, intensive mostly mechanical ploughing is applied in, for instance, vegetable production. The area has loess soils, which with intensive ploughing are susceptible to erosion. The study aims to determine changes in the quality of flowing waters against the background of agricultural production and land-use characteristics. Surface waters were classified as class II and occurred at all analysed points. The highest concentrations of N-NO_3, N-NH_4 and P-PO_4 were found at a point in the middle of the catchment (lower part of research area). There, the lowest concentrations were recorded in 2018, which was related to the amount of precipitation during the growing season. On the other hand, the volume of plant and animal production closely correlated with the quality of surface water in the area. This was also confirmed by the land use structure. In conclusion, intensive agricultural production, mainly in terms of plough tillage causes significant hazards associated with soil erosion especially on agriculturally sensitive soils, although it provides good yields.

Keywords: agrarian structure, intensive agricultural production, land use, surface water quality, Szreniawa River catchment

INTRODUCTION

The technological progress appears to be the main determinant with positive influence on economic growth and larger agricultural yields. Although the use of technological innovations, such as mechanisation and fertilisers, can have significant long-term positive effects on agricultural production, it can pose a threat to the environment. The structure of land use, especially agricultural use, can also influence the quality of ground and surface water [Islam *et al.* 2022; Kopacz 2003; Liu *et al.* 2022]. In agricultural areas, structural and spatial changes that have taken place in the last 30 years in our country have caused major transformation of the natural environment, including water and soil.

The chemical composition of surface waters in agricultural areas depends on anthropogenic and natural factors [Jakubiak, Bojarski 2021; Ma *et al.* 2009; Sapek 1996]. Field crops take up only part of fertiliser nutrients supplied to them. In the year of fertilizer application, nitrogen utilisation from mineral fertilisers is 50–70%, and from natural fertilisers 20–30%, phosphorus 20–30%, potassium – 50–60% of the applied dose [Ilnicki 2004]. Some of fertiliser compounds runoff into surface and underground waters causes their degradation.

The development of agriculture and overdosing of chemical fertilisers significantly increase the content of mineral components in runoff waters from agricultural areas. This results in excessive fertilisation of surface waters, which leads to eutrophication [ADAMCZYK, JOACHIMOWSKI 2013; MARARAKANYE *et al.* 2022].

Water from reservoirs in agriculturally used areas is characterised by 2.0–4.5 times higher content of total nitrogen (N) in comparison with waters in seminatural areas. Infiltration of nutrient compounds into surface waters from agricultural areas depends mainly on the type and intensity of agricultural production, as well as the susceptibility of soils to erosion and their permeability. Soils with high utility value have great potential for good yields. This, however, may be associated with an area-wide threat to surface waters from nitrogen and phosphorus compounds, which are the main eutrophication factors [PURNELL *et al.* 2014; SMOROŃ 2012; THEBO *et al.* 2017].

Compared to other crops, the cultivation of vegetables is characterised by low utilisation of fertiliser components, especially nitrogen, and high losses [HARTZ 2006; NETT 2012]. The next factor affecting water quality is agrotechnology, including mainly mechanical soil cultivation. Loess soils that are used and left for a significant part of the year without sufficient cover are subject to a variety of soil erosion processes. In the area of the Proszowice Plateau, agricultural activity (especially ecological agriculture of medium intensification) may be combined with the preservation of landscape diversity, especially biodiversity, based on small, island habitats in agricultural areas [DRUŻKOWSKI 2004; KOPACZ *et al.* 2021a, b].

Intensive farming has a negative impact on sustainability. Excessive exploitation of natural resources can be observed. In such areas, depletion of plant cover and reduction of terrain biodiversity can be recorded [BASTIAN, BERNHARDT 1993; KRONERT *et al.* 1999]. This study aimed to assess the quality of surface waters and the load of biogenic pollutants in comparison with the land use structure in the drainage basin of the Szreniawa River.

STUDY MATERIALS AND METHODS

The study area of 712 km^2 covered the southern part of Poland in the catchment of the Szreniawa River (Fig. 1). It is located on the Upland in Olkusz, in the Miechow and Proszowice Plateau. The Szreniawa River is approximately 80 km long and is a left-bank tributary of the Vistula River. It begins its course in the peat bog near Wolbrom (Upland in Olkusz at 380 m a.s.l.) and flows in a south-eastern direction, discharging into the Vistula at 178 m a.s.l., which accounts for about 200 m difference in elevation [SMOROŃ, KOWALCZYK 2014]. In 2017-2021, water samples for chemical analysis were collected monthly from four points: in the lower part of the research area (middle part of catchment) (point 1 – in Proszowice), middle (point 2 – in Ścieklec-Makocice and point 3 – in Słomniki), and upper part of the catchment (point 4 – catchment below Cichy stream).

The share of arable land in the farmland structure exceeds 90%, and permanent grassland is less than 8.0% [KOWALCZYK, KOPACZ 2020]. The area is covered by very fertile loess loam soils, classified as the proper and degraded chernozem and proper brown soil, whereas in river valleys the area includes swamps [BROAD, CORKREY 2011]. Their usable value is high and falls within the I–IIIb soil standard, with the predominance of very good wheat and good wheat agricultural suitability complex. This area is threatened by water erosion, which is characteristic for undulating loess areas [SMOROŃ, KOWALCZYK 2014]. According to the CORINE database (2018), the structure of land use is as follows: 72.6% arable land beyond the reach of irrigation facilities, 48.29% complex systems of crops and plots, and above 43% is urban development, and meadows and pastures (Fig. 2).

The research points have been designed according to the following rules: catchment system – upper, middle and lower part of the catchment:

- characteristics of land use – the upper part of the research catchment – typically forests,

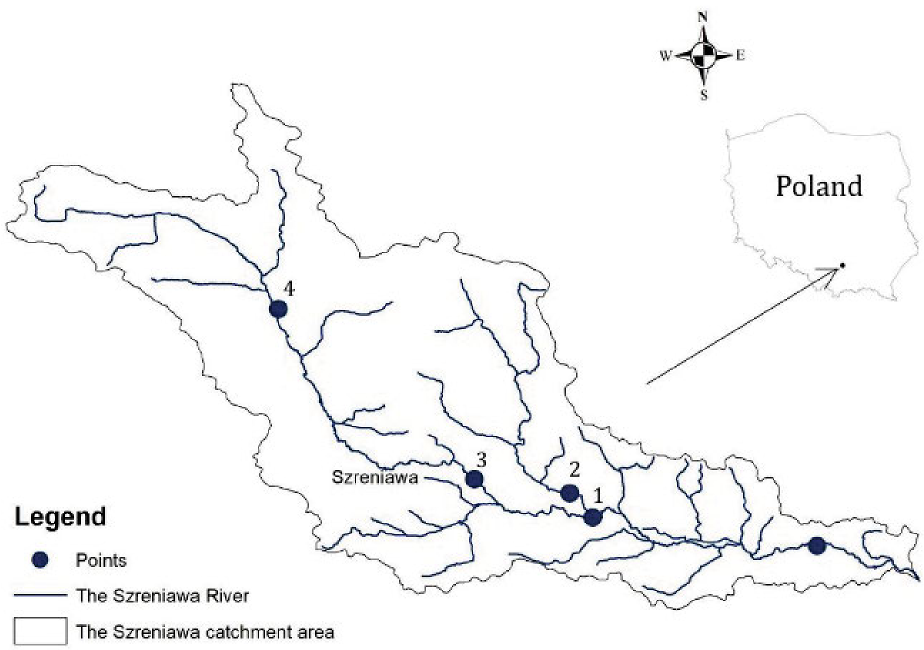

Fig. 1. Szreniawa River basin and measurement points; source: own study

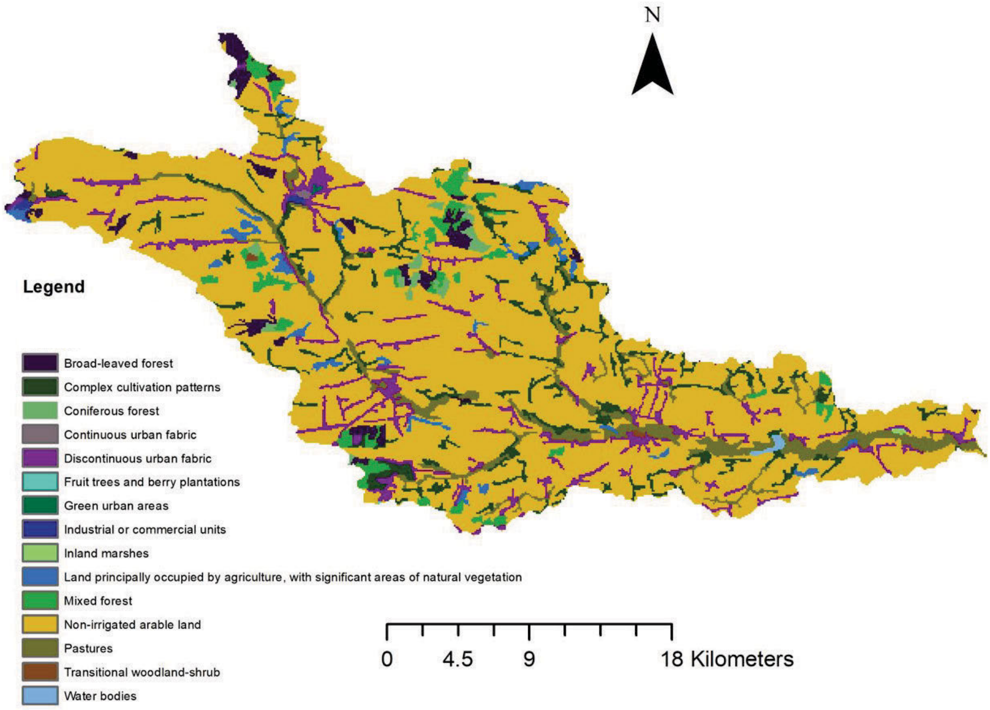

Fig. 2. Land use structure in the Szreniawa catchment according to the CORINE database (2018); source: own study

– the middle part of the catchment: increase in the share of agricultural land,
– the bottom part of the catchment: agricultural (mainly arable land) and generally arable land exposed to emissions from the entire catchment area.

The average general quality index of the agricultural production space in the catchment is high and ranges from 81.5 to 101.1 [Witek *et al.* 1994; Yan *et al.* 2022]. Due to the type of soil and surface topography, the area is classified as highly threatened by water erosion.

Analyses of water samples were performed at the Laboratory of the Institute of Technology and Life Sciences, National Research Institute, Branch in Cracow (Pol. Laboratorium Instytutu Technologiczno-Przyrodniczego – Państwowego Instytutu Badawczego, Oddziału w Krakowie). In water, concentration of N-NO_3, N-NH_4, and P-PO_4 were determined by generally accepted methods with a photometer using powder reagents.

The results are presented as mean concentrations of the components over the study period for each water measurement point. The dispersion of monthly concentrations around the mean for the whole study period (standard deviation) has been calculated.

The water quality limits are adopted following the Regulation of the Minister of Infrastructure of 25 June 2021 on the classification of ecological status, ecological potential and chemical status and the method of classification of the status of surface water bodies, as well as environmental quality standards for priority substances [Rozporządzenie… 2021].

RESULTS AND DISCUSSION

The analysed N-NO_3, N-NH_4 and P-PO_4 concentrations (Fig. 3, Fig. 4) were presented graphically using the R package [The R Development Core Team 2022]. The data were referred to the Regulation of the Minister of Climate and Environment of 25 June 2021 on the classification of ecological status, ecological potential and chemical status and the method of classification of the status of surface water bodies, as well as environmental quality standards for priority substances [Rozporządzenie… 2021]. The results indicate that the limit values for water class II (0.8 N-NO_3·dm^{-3}) and class I (0.5 mg N-NO_3·dm^{-3}) were significantly exceeded at all sampling points. The highest concentrations were found at sampling point 4 below Cichy where values were above 10 mg N-NO_3·dm^{-3}.

Although still in excess of class I and class II standards, the lowest concentrations were recorded in 2017 and 2018; values ranged from 1.11 to 1.33 mg N-NO_3·dm^{-3}. The drought during the growing season and the low amount of rainfall might be a possible reason for the lower concentrations. Studies usually show decrease in concentrations during high water levels due to the dilution of pollutants. However, the structural specificity of the catchment suggests slightly different conclusions. The lack of rain or its small amount limits considerably the surface runoff in this catchment. Surface runoff is the largest "carrier" of material eroded from the surface of arable fields. Therefore, less precipitation reduces the runoff of nutrient loads in the catchment [Kowalczyk *et al.* 2019]. This was most likely the reason for the reduction in the concentration of pollutants in surface water in the present case.

Similar to nitrate nitrogen N-NO_3, P-PO_4 concentrations exceeded class II in all cases (i.e. $\leq$0.04 mg·dm^{-3}) and ranged from 0.16 to 0.25 mg·dm^{-3}. In previous years, the highest concentrations were also recorded at points 1 and 3 (approximately 0.5 mg·dm^{-3}). The standard deviation value varied strongly and ranged from 0.04 to 0.55. The slight deviation from the mean concentration was recorded at point 2 in 2019. As with nitrate nitrogen, phosphate ion concentrations were the lowest in 2018. The most likely cause of the phenomenon has been described above in the context of nitrogen compounds.

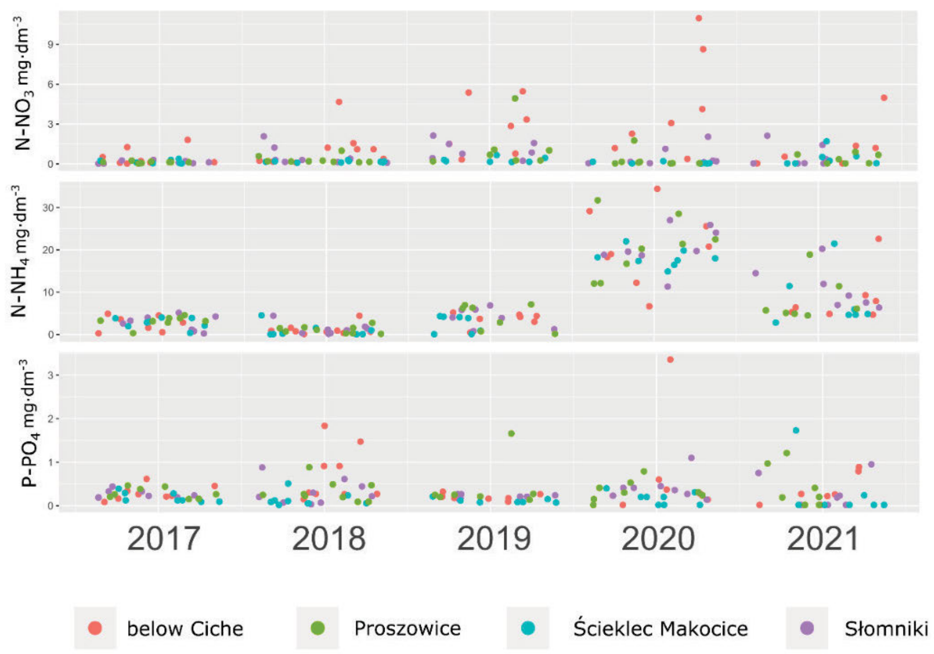

Fig. 3. Annual average concentrations of N-NO_3, N-NH_4 and P-PO4; source: own study

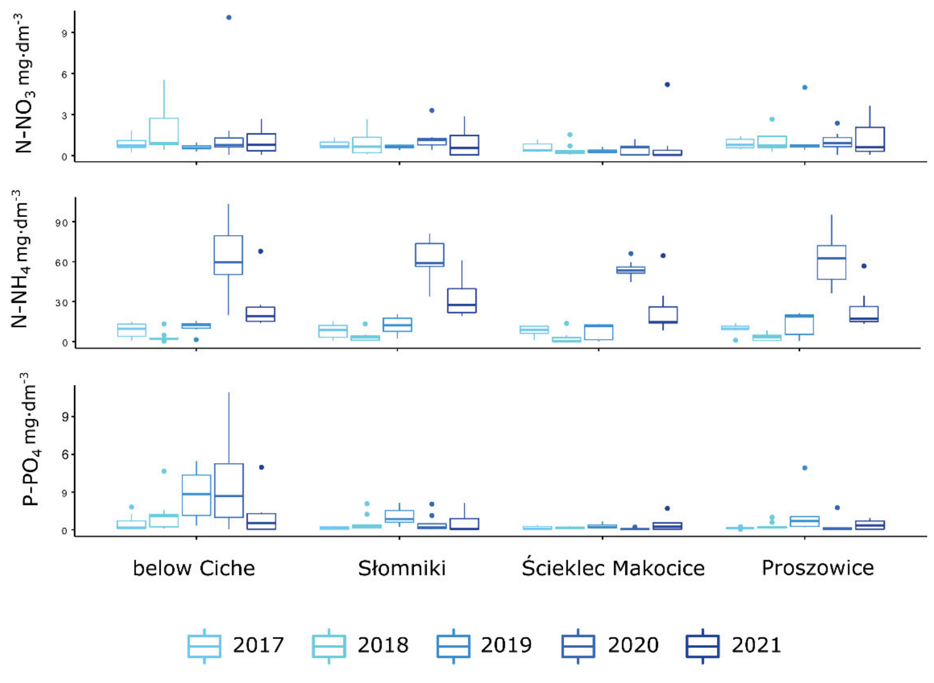

Fig. 4. Standard deviations of the measurements N-NO_3, N-NH_4 and P-PO_4; source: own study

The concentrations of ammonia nitrogen, an indicator of the biochemical decomposition of organic nitrogen compounds, were also determined in the water samples. Like phosphate, the highest concentration of N-NH_4 (about 3.0 mg·dm^{-3}) was recorded at sampling point 4 (Fig. 1) in 2020. Concentrations at all sampling points exceeded class I, i.e. ≤0.04 mg·dm^{-3}, while concentration values at the same point in 2017 and 2019 exceeded class II (≤0.20 mg·dm^{-3}). The standard deviation for concentration values was also highly variable, ranging from 0.06 to 1.68.

The land use data in individual counties were obtained from the Local Data Bank of the Central Statistical Office. These data were converted from an administrative system to the catchment system with the use of a special calculation matrix. Data processing allowed to obtain area values and percentages of particular land use types for the catchment (Fig. 5). Over 92% of the catchment area is arable land. The catchment has a typically agricultural, almost plough-like character. Agricultural land in good agricultural condition accounts for 89%, and 79% is used for sowing. Permanent grasslands, orchards and pastures represent about 1% of the catchment area, while home gardens 0.3% (Fig. 5).

Sowing structure in the Szreniawa catchment area is presented in Figure 6. Cereals have the highest share in arable

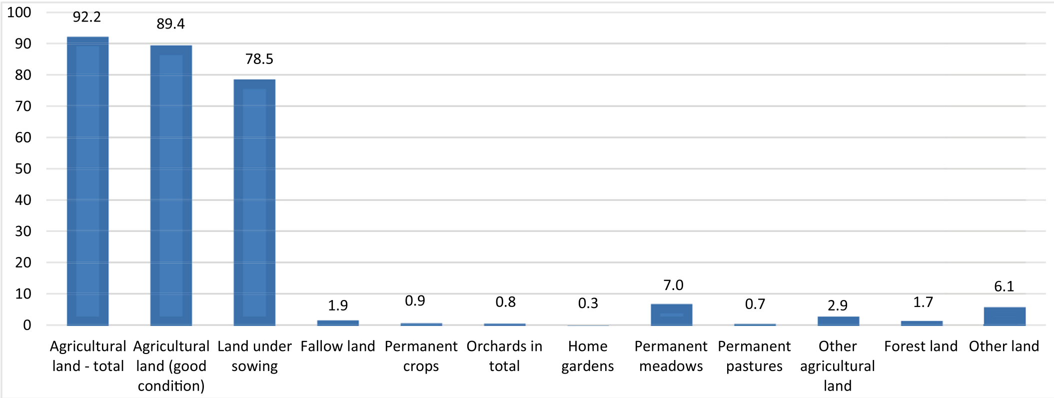

Fig. 5. Land use structure (%) in the Szreniawa River basin; source: own study

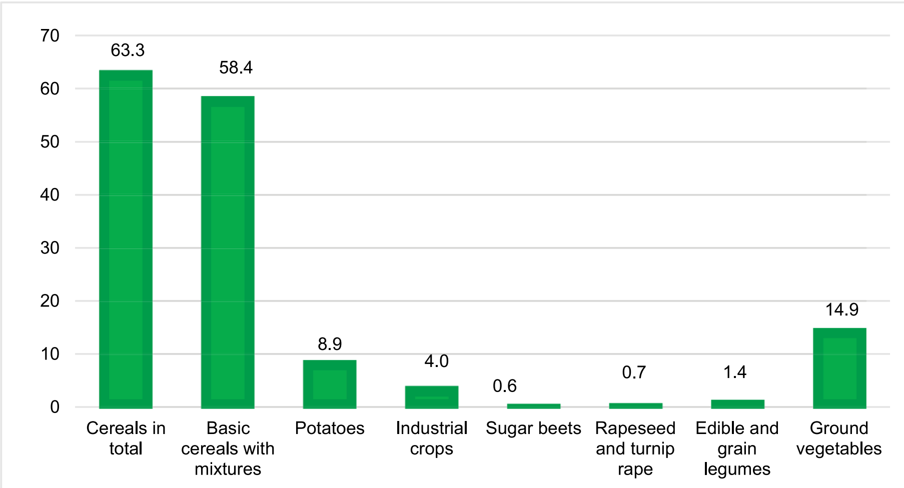

Fig. 6. Structure of field crops (%) in the Szreniawa catchment area; source: own study

land cultivation (more than 63%), potato crops account for almost 9% and industrial about 4%. Vegetable plantations cover 14.9% of arable land. The share of vegetable production is very high due to the specific nature of this type of agriculture. As mentioned earlier, the agricultural area of the Szreniawa River basin has traditionally played an important role of a "vegetable basin" supplying food products to the Cracow agglomeration and its surroundings.

The analysis of the animal husbandry structure in the Szreniawa River catchment area has shown the domination of dairy cattle and poultry. However, the whole livestock production remains at an average level. After converting the livestock population in the catchment into so-called large livestock units (LU), it can be concluded that there are 59.272 LU in the whole catchment (as of 2019). This means that approximately there are about 60.000 adult dairy cows of an average weight of 500 kg. In the whole catchment area there are 1.28 LU·ha^{-1} of arable land. According to the Nitrates Directive, a threat of pollution with nitrogen compounds of agricultural origin appears when the stocking rate per 1 ha of arable land exceeds 1.5 LU [Council Directive 91/676/EEC]. Considering that the catchment is a typically agricultural area with very advanced plant production, 1.28 LU per ha of arable land is a moderate value. This confirms the assumption that the Szreniawa catchment is mainly used for plant production, including vegetable plantations.

CONCLUSIONS

The catchment area of the Szreniawa River is characterised by intensive agriculture. In addition, the unfavourable structure of soils (loess) makes this catchment subject to very dangerous and violent erosion phenomena. They can be quite intensive during high precipitation.

These conditions affect the quality of water, both ground and surface. In particular, the high proportion of arable land (more than 90%) threatens the aquatic environment. Intensive ploughing together with unfavourable soil conditions and the aforementioned erosion processes exacerbate the poor condition of water. Significant leaching of nutrients (N-P-K) from arable surfaces of the catchment and the lack of vegetation cover result in significant eutrophication of waters.

The highest concentrations were found at the mouth of the river. This also depended indirectly on the amount of precipitation. Moreover, the amount of crop and livestock production correlated with the surface water quality.

The structural peculiarity of the catchment meant that the lack of precipitation or its scarcity limited the volume of surface runoff, and consequently the volume of material eroded from agricultural fields was limited, and the nutrient load discharged from the catchment was much lower.

This is indicated by the results obtained for P-PO_4, which exceeded class II in all cases. Concentrations of ammoniacal nitrogen, an indicator of biochemical decomposition of organic nitrogen compounds, were similar to other compounds.

Considering unfavourable soil conditions, more than 92% of the arable land necessitate a change in management. This is because the ecological priority is to reduce the load of biogenic pollutants entering the catchment area. Agricultural production should therefore include greater proportion of grasslands and the use of those parts of the catchment where erosion and leaching of NPK components is the highest should be revised as it translates directly into the water quality status.

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