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Impact of Land Use on Stream Water Quality in the German Low Mountain Range Basin Gersprenz

Abstract

Knowledge of the interactions of hydrological processes with the landscape are important to understand variations in basic hydrological data for the comprehensive management of basins. Land cover and land use is one essential factor in the assessment of such management problems. In this study in a representative German basin, available land cover and land use data is analysed in correspondence with available hydrological measuring data.

The aim of this study is to analyse the relationships between hydrological data and land use and to obtain a monitoring strategy which allows a valuable support to a comprehensive management of river basins. Two spatial scales, the basin Gersprenz and its subbasin Fischbach, are described in detail regarding the variations in electrical conductivity (EC) as a parameter of water quality with high resolution field data from the state-wide monitoring network (12 stations) as well as from own research monitoring (12 stations). The results show that water quality, using EC as an indicator, can be related to land use pattern. From stream source to mouth, there is an increase in anthropogenic impacts and the EC values show an increasing tendency in downstream direction. This anthropogenic impact is due to agricultural use, settlements, commerce and industry areas, and discharges of waste water. The hydrological monitoring will be continued in the future to give the possibility to assess long-term variations on different spatial and temporal scales.

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1 Introduction

For the understanding and analysis of hydrological processes and interactions, small hydrological research basins are operated worldwide by universities, research institutes and authorities of the environmental administration. Schmalz et al. (2015) evaluated 38 study basins ranging from 0.06 km² to 50 km² in the German speaking countries in Central Europe and analysed the need for high resolution measuring data and long-term data series as well as regular data update. This study points out the valuable contributions of a continuation of smaller hydrological study basins for the future in the areas of research, teaching and environmental policy debate.

As formulated in the "Braunschweig Declaration" in 2010 (IHP/HWRP, 2010), there is a need for a global network of long-term operated small hydrological basins. Based on the review of Schmalz et al. (2015), the requirement for high-resolution measuring data and long-term data series is needed especially for:

- the understanding of hydrological processes,
- the identification of influencing factors on hydrological processes,
- model application and development, model testing for sensitivity and uncertainties,
- the display of changes like climate and land use change, land management and water resources management.

Furthermore, the network of small hydrological research basins enables the integrated and / or interdisciplinary evaluation across research questions and the exchange of knowledge and methods. Additionally to a comprehensive and well operating measuring network, land cover and land use play an important role for hydrological processes and water quality. Both compartments should be analysed and discussed together in terms of a basic study design.

Land cover and land management in a river basin usually have an influence on hydrological processes, water balance and water quality. In order to get a first impression of the impact of land use on river water quality, an analysis of both components and their interaction must be carried out. These relationships have already been investigated in previous studies, also for the state Hesse in Germany. Thus, Hietel et al. (2004) analysed land-cover changes in relation to environmental variables for the period 1945 to 1998 in the Lahn-Dill Highlands. The environmental variables cover elevation, slope, aspect, available water capacity, soil texture, patch size, patch shape, and patch distance. Peter and Harrach (1993) investigated the impact of land utilisation on nitrate leaching in North Hesse (Kellerwald forest, 1990-1992). Their results show that an increased nitrate leaching usually can be attributed to excessive fertilising of poor soils with low productivity. Also Lenhart et al. (2003) analysed the impact of land use changes on nitrate by different scenarios in a modelling study. For the Dill catchment an increase of nitrate output due to increasing deforestation and land use intensity was calculated.

In order to avoid costly laboratory analyses, to collect continuous monitoring data and to get a first impression of the extent to which water quality is affected, electrical conductivity (EC) was continuously measured in situ using sensors in some studies. EC is related to the concentrations of total dissolved solids and major ions (Chapman, 1996). Several authors stated that water quality can be evaluated by a single parameter such as EC (e.g. Ghorbani et al., 2017), that EC is a rough indicator of mineral content when other methods cannot easily be used (Chapman, 1996) and that continuous monitoring of EC in surface or subsurface water sources has proven to be very useful (Eiche et al. 2016; Chapman 1996).

Agricultural practices affect EC: Chapman (1996) suggested to include EC among others in water quality assessment programmes, as impacts relating to agricultural activities principally concern organic and inorganic matter and those chemicals incorporated in fertilisers and pesticides as well as salinisation due to irrigation. In a study by Diamantini et al. (2018)

EC shows high positive correlations with agricultural land use (Sava basin as southern part of the Danube basin). Furthermore, in a study area in southern Poland, EC is positively correlated with arable lands, built-up areas and negatively with meadows and pastures (Lenart-Boroń et al. 2017). Additionally, in a lightly developed area of upstate New York, EC strongly correlated highly and positively with urban development (Halstead et al. 2014).

Hydrological analyses and models need data, which must be on the one hand continuously measured over a long time and on the other hand spatially explicit. By means of these data series and additional mapping, process studies can be conducted, matter input sources and pathways into water bodies can be analysed and models can be developed and applied. In combination with the analysis of scenarios, integrative river basin management strategies can be developed.

In the state Hesse in Germany, the Gersprenz basin and its subbasin Fischbach were selected as a so-called field laboratory or field observatory by ihwb (Chair of Engineering Hydrology and Water Management) from TU Darmstadt in 2016 and serves as a case area for this study.

Therefore, our objectives for this German case study are

- to depict and analyse the characteristics of a representative basin in the German low mountain range area by available data and

- to assess the interplay between land use data series and hydrology, in particular using EC as one possible indicator.

2 Hydrological research basin Gersprenz

2.1 Gersprenz basin

The field laboratory selected for our studies covers the Gersprenz basin in Hesse up to the border with Bavaria (see Figure 1). The catchment area of 485 km² was determined by the digital elevation model with 5 m resolution. However, some minor corrections were applied manually (near roads and bridges). It is part of the river basin district Rhine. River Gersprenz originates in the low mountain range area Odenwald and discharges into the river Main at Stockstadt / Main. The natural environment includes areas of the crystalline basement of the Vorderer Odenwald, of hilly landscape (Reinheimer hill country) and of lowland areas of the lower Main region. Therefore, the difference of altitudes of this low mountain range area is between approx. 600 m asl. and around 100 m asl.

The Crystalline Odenwald is characterised by the uncovered crystalline basement, which has a large variety of rocks such as metamorphic gneisses, diorites and granites as well as plutonic gabbros or volcanic rhyolites and basalts. In the plain of the Lower Main River, the soils consist predominantly of tertiary deposits such as gravel, sand and clay covered by younger river deposits as well as loess and aeolian cover sands. The Messel hill country located in the north-west is characterised by the Rotliegend, in the eastern area, there is the Sandstone Odenwald (RP DA 2015).

49% of the entire catchment is under agricultural land use, 38% is covered by forests and ca. 8% by settlements and traffic areas (RP DA 2015). Further settlements are Reichelsheim, Brensbach, Groß-Bieberau, Reinheim, Groß-Umstadt, Babenhausen and Stockstadt / Main.

The stream source of river Gersprenz is a natural monument and is located on the Neunkircher Höhe. The upper section of river Gersprenz is called Mergbach. After merging with the Osterbach, river Gersprenz flows north and downstream of the city of Dieburg into northeastern direction and discharges after 62.2 km into river Main at the municipality of Stockstadt / Main (WV Gersprenz 2017).

Several larger and smaller tributary streams, e.g. Semme, Lache, Fischbach and Wembach, flow into river Gersprenz. Further hydrological elements are ponds, mill channels and moats. Retention areas were constructed for flood spillway, e.g. in the districts of Groß-Zimmern, Groß-Bieberau and Hergershausen.

2.2 Fischbach subbasin

The Fischbach subbasin covers 35.6 km². Fischbach is a small coarse substrate dominated siliceous highland river (Type 5). It originates in the outskirts of Modautal-Lützelbach, flows into northeastern direction through several built-up areas of the municipality Fischbachtal and discharges after nearly 10 km into Gersprenz at Groß-Bieberau. The elevation changes about 250 m along the stream from spring to mouth, but the elevation within the entire Fischbach basin ranges from 162 to 592 m a.s.l. Other contributing streams are Rodauer Bach, Steinbach, Nonroder Bach, Messbach, amongst other. In the previous centuries, the water of Fischbach powered at least eight water mills (Fischbachtal 2017). For flood alleviation to be protected from HQ50 (return period of 50 years), another retention area called Herrensee / Fischbachtal, was developed with a reservoir surface area of approx. 10 ha and a holding capacity of around 220,000 m³ (WV Gersprenz 2016).

3 Methods

3.1 Screening and processing available land use data

The first step was the acquisition of available data for information on land use and land cover.

Several data sets of varying spatial and temporal resolution are available for Germany. Here, the official German data set ATKIS ("Amtliches Topographisch-Kartographisches Informationssystem"; Authorative Topographic-Cartographic Information System (ATKIS®), HVBG 2017) is used for the representation of the current share of land cover / land use classes. The data set was provided by the state authorities. All spatial data was analysed with a geographical information system (GIS). For the entire Gersprenz basin and the subbasin Fischbach, all existing polygon data was extracted to calculate the respective share of land cover and land use class. The polygons were grouped according to the most relevant classes for the hydrological analysis, i.e. they are grouped according to the usually applied land cover / use classes from ATKIS. For example, even though very detailed information on the urban structures are available (e.g. streets, parking lots), all relevant polygons are grouped into the class "settlements, industry and traffic". The most details are extracted for the classes of agriculture and forest areas (i.e. coniferous, deciduous and mixed forest). In this study, the classes arable land, grassland, vineyards, tree nursery and orchard were grouped as "agriculture".

3.2 Hydrological field studies and measurement data

Hydrological data (e.g. water level and discharge, water quality incl. biological quality components, such as macroinvertebrates, fish and diatoms, cp. HLNUG 2017b) is measured and monitored by different institutions and for several sampling locations within the basin.

Field data is provided by state authorities (HLNUG) and completed by own measuring data from ihwb of TU Darmstadt for this study.

The state of Hesse monitors water level and discharge data at both Gersprenz gauges Harreshausen (since 1955; basin area = 463 km²) and Wersau (since 2006; basin area = 102 km²) (according to HLNUG 2017a). The gauge Groß-Bieberau 1 was replaced by the upstream located gauge Wersau. Further gauges of the water board in Groß-Umstadt and Unter-Ostern complete the data set basis.

In general, for assessing water quality, there are further hydrochemical and biological measuring points from the state of Hesse (HLNUG, 2017b, 2018a). Periodic, random water sampling is carried out usually on a monthly basis. In contrast to continuous measurements, this method only provides a snapshot of the water quality. However, it has the advantage that a dense network of measuring stations distributed throughout Hesse can be investigated. Each time a sample is taken, the parameters oxygen, temperature, electrical conductivity and pH are recorded directly on site, further parameters such as filterable solids, nitrogen, phosphorus and TOC (total organic carbon) are analysed in the laboratory (HLNUG, 2018a). For this study, the electrical conductivity from 12 HLNUG stations within the period 2008-2017 were analysed (Figure 1, Table 1). They cover four measuring points in the Gersprenz main channel and eight measuring points in tributaries of the Gersprenz river. Their measurement results are depicted separately in Figure 4 and Figure 5.

The parameter electrical conductivity (EC) is used for the summary recording of the cat- and anions dissolved in the water. This makes it possible to monitor the stream water quality and link it to the surrounding geology, land and water use and different waste-/water discharges.

The gauge Groß-Bieberau 2 in the Fischbach stream is located 1.2 km from the mouth into Gersprenz and correlates to a basin of 35.4 km² (HLNUG, 2017a). Here, water level and discharge are measured continuously (since 1974).

For assessing the chemical water quality, one of the above mentioned 12 stations of the entire Gersprenz basin is located in the Fischbach (Groß-Bieberau), but directly at the confluence with the Gersprenz (not identical to the gauge Groß-Bieberau 2).

Since 2016, ihwb measures relevant parameters, which complement the official data of Hesse and literature data. The measurement concept is two-parted, which contains a continuous monitoring at few selected locations and a short-term monitoring with less temporal resolution but higher spatial resolution.

Continuous measurements are conducted at relevant points in the basin. Therefore, ihwb installed sensors for measuring water level, water temperature and electrical conductivity at the gauges Harreshausen (multiparameter sensor SEBA Qualilog-8), Wersau and Groß-Bieberau 2 (SEBA Dipper PTEC).

To obtain additional spatial information, a weekly measuring campaign at 12 measuring points in the Fischbach stream is conducted (Figure 2, Table 2). Here, water depth and flow velocity (since October 2016) as well as electrical conductivity (since February 2017) are measured. This data series enables the analysis of spatial and temporal variability in the water courses.

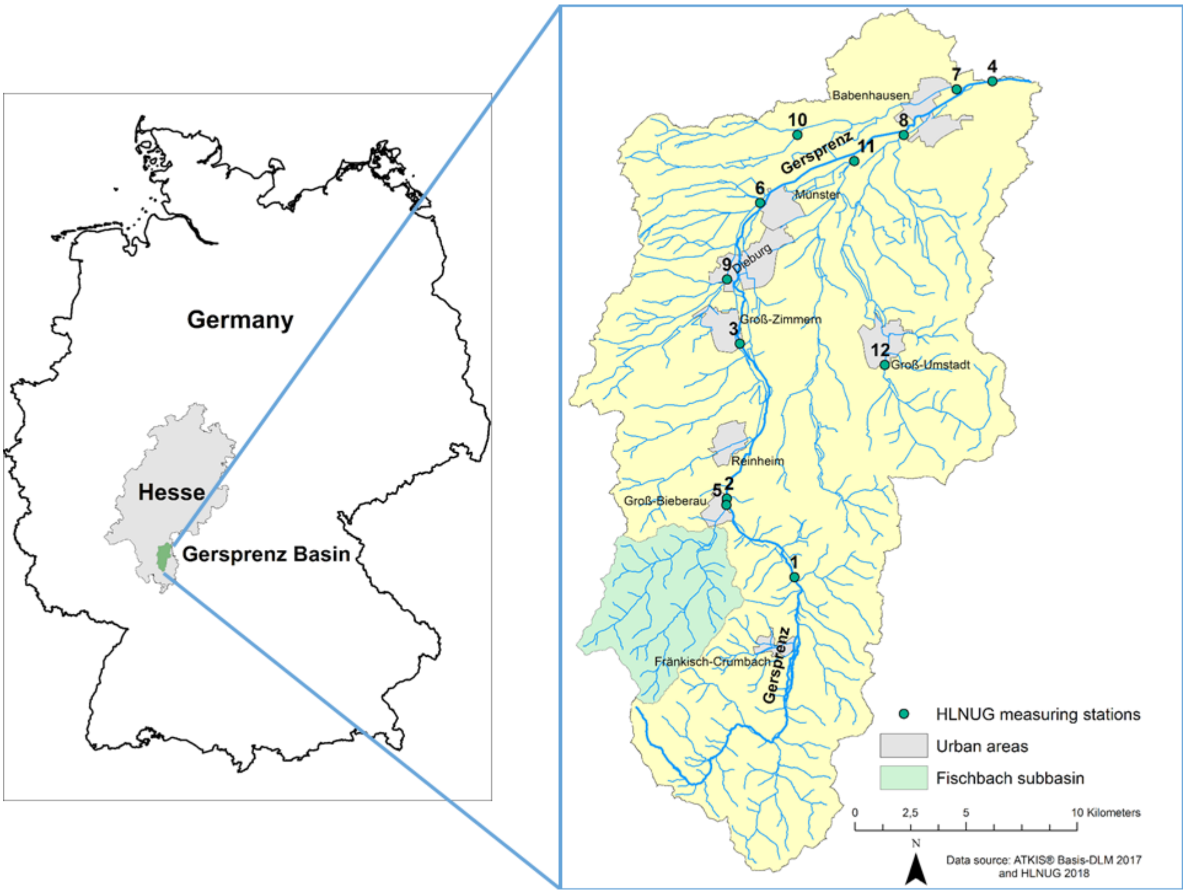

Figure 1: Location of the Gersprenz basin in Germany / Hesse (left) and the sampling points from HLNUG in the entire Gersprenz basin (right) (after HLNUG 2018a) with main urban areas for orientation (note that the Fischbach subbasin refers to the gauge Groß-Bieberau 2 as in Figure 2 and not to station 5)

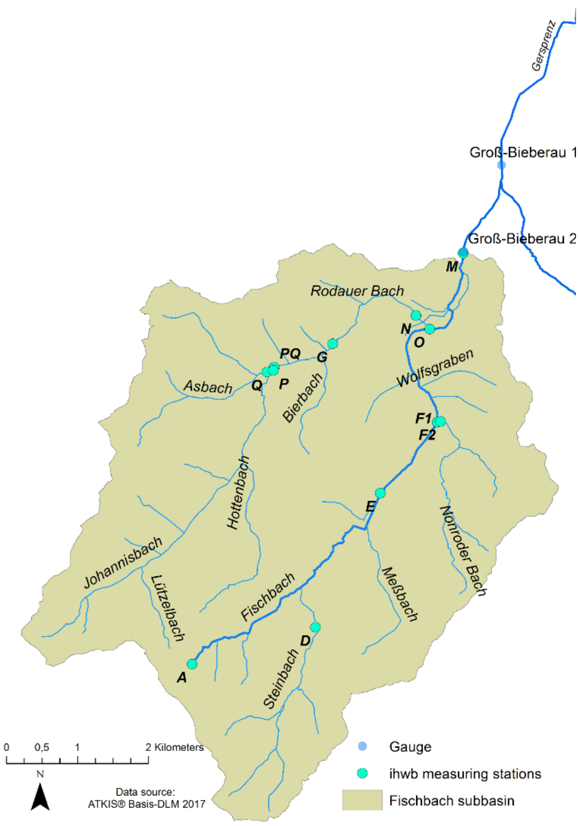

Figure 2: Location of the sampling points from ihwb in the Fischbach subbasin

Table 1: Measuring stations for electrical conductivity from HLNUG in the entire Gersprenz basin (station ID see Figure 1; HLNUG 2018a)

Station ID	Measuring stations HLNUG	River/stream	Data availability / analyses	Surrounding land use
1	Brensbach	Gersprenz	2009-2011, 2014-2015, 2017	Grassland / Settlement
2	Bieberau	Gersprenz	2008-2009	Agriculture / Vegetation
3	Klein Zimmern	Gersprenz	2008, 2010-2017	Grassland / Settlement
4	Harreshausen	Gersprenz	2008-2017	Vegetation / Agriculture
5	Groß-Bieberau	Fischbach	2014-2015, 2017	Settlement / Grassland
6	Münster	Stillgraben	2008, 2011-2013, 2015-2017	Agriculture / Vegetation
7	Babenhausen	Lache	(2011), 2012-2014, 2016-2017	Agriculture / Vegetation
8	Babenhausen, upstream of water mill	Ohlebach	2008-2011, 2013-2014, 2016-2017	Agriculture / Settlement
9	Dieburg	Erbesbach	2008-2011, 2013-2017	Settlement / Agriculture
10	Babenhausen-Hergershausen	Hegwaldbach	2008-2014, 2016-2017	Forest
11	Hergershausen	Semme	2009-2013, 2016-2017	Settlement / Grassland
12	Groß-Umstadt	Pferdsbach, upper Ohlebach	2010, 2012, 2014-2015, 2017	Settlement / Grassland

Table 2: Measuring stations from ihwb in the Fischbach subbasin (station ID see Figure 2)

Station ID	Measuring stations ihwb	River/stream	Surrounding land use
A	Lützelbach (spring)	Fischbach	Settlement / Grassland
D	Steinau	Steinbach	Settlement / Grassland
E	Messbach (Herrensee)	Fischbach	Grassland
F1	Niedernhausen (Schnurrgasse)	Fischbach	Settlement
F2	Niedernhausen	Nonroder Bach	Settlement
G	Rodau	Rodauer Bach	Settlement
M	Groß Bieberau (gauge)	Fischbach	Settlement
N	Groß Bieberau / Rodau	Rodauer Bach	Vegetation / Arable land
O	Groß Bieberau / Rodau	Fischbach	Mixed forest
P	Rodau	Johannisbach	Settlement
Q	Rodau	Asbach	Settlement
PQ	Rodau	Rodauer Bach (confluence of P and Q)	Grassland

4 Results

4.1 Analysis of the entire Gersprenz basin

4.1.1 Land use

The ATKIS data set was used to represent the share and distribution of all land use classes of the Gersprenz basin in a map (Figure 3) and to calculate the areas for each land use class (Table 3).

Agriculture is the dominant land use in the Gersprenz basin (48.3%) with mainly arable land but also grassland. Grassland occurs more frequently in the southern part with higher topography. A subordinate role play vineyards, orchards and tree nurseries which are distributed throughout the basin as smaller land use areas. In the forest areas, mixed forests prevail and deciduous forest plays a minor role. Further vegetated areas, e.g. groves under no specific use, exist along roads and between arable land. Some smaller water bodies and some open pit

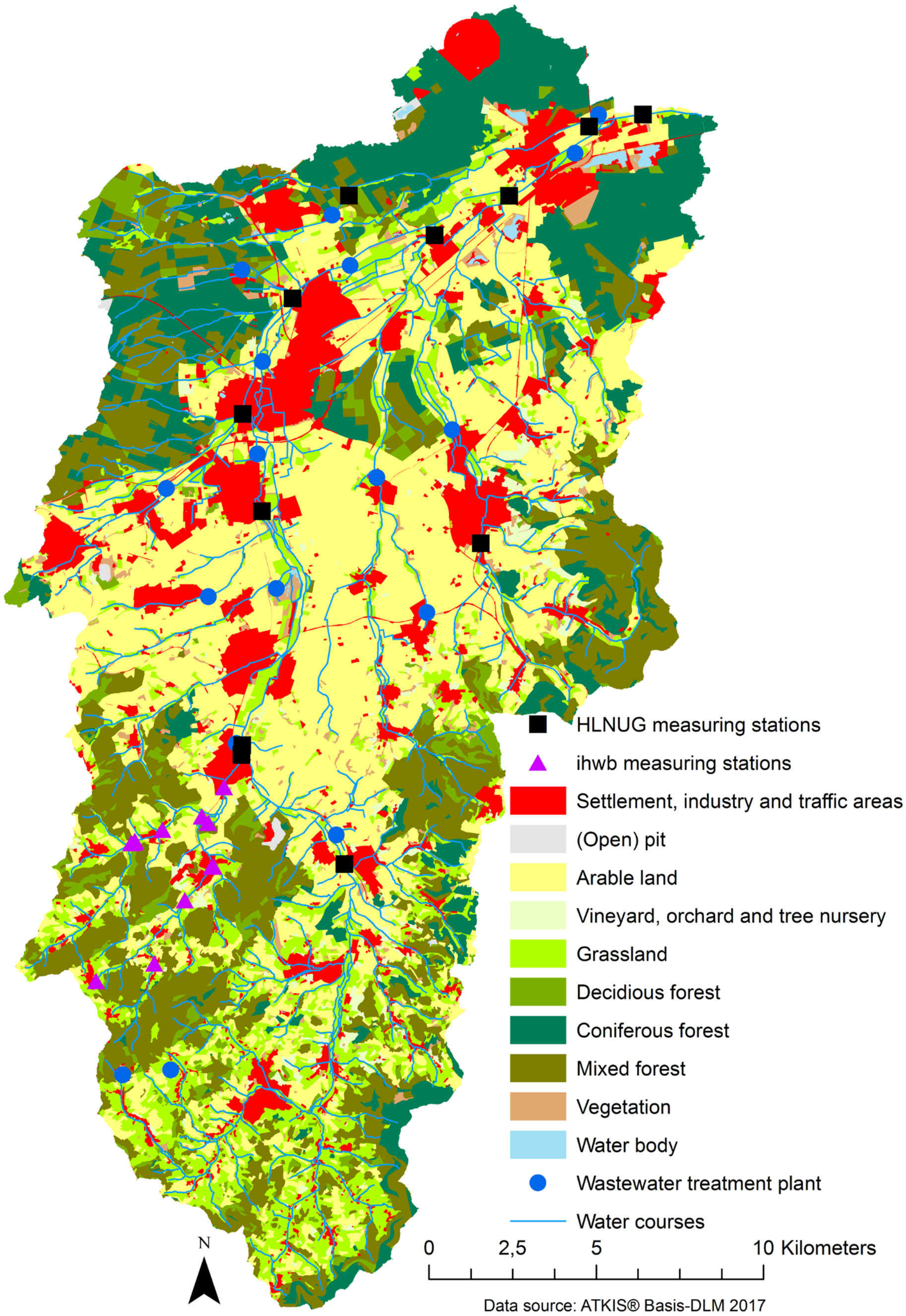

Figure 3: Water courses and land use in the Gersprenz basin based on the ATKIS data set (data source: ATKIS®Basis-DLM 2017) and location of the sampling points from HLNUG in the entire Gersprenz basin (HLNUG 2018a)

areas occur as well. The settlements include industry and commerce areas and traffic and these areas are more dominant in the northern part.

Figure 3 shows also 17 wastewater treatment plants located in the basin (based on ATKIS data). Thereof, nine are communal wastewater treatment plants with design capacities between 8900 and 40000 population equivalents (HLNUG 2018b).

4.1.2 Hydrological studies and results

As an indicator of water quality, the measured conductivity data was analysed. Figure 4 shows EC values from 2008-2017 (different time periods) in the Gersprenz main channel, ranging from 170 µS/cm (1_Gersprenz-Brensbach) to 854 µS/cm (3_Gersprenz-Klein Zimmern) with mean values of 287 µS/cm (1_Gersprenz-Brensbach), 413 µS/cm (2_Gersprenz_Bieberau), 475 µS/cm (3_Gersprenz-Klein Zimmern) and 572 µS/cm (4_Gersprenz_Harreshausen) (HLNUG 2018a). There is a tendency of increasing EC values in downstream direction.

Figure 5 shows EC values for the tributaries of the Gersprenz, ranging from 170 µS/cm to 1459 µS/cm (both 8_Ohlebach; HLNUG, 2018a). The mean values are lowest in 5_Fischbach (396 µS/cm), but highest in 9_Erbesbach (904 µS/cm) and 8_Ohlebach (808 µS/cm).

Table 3: Land use classes and area in the Gersprenz basin (data source: ATKIS®Basis-DLM 2017)

Land use class	% land use area
Settlement	12.6
Open pit, quarry	0.1
Arable land	32.6
Vineyard, orchard, tree nursery	1.9
Grassland	13.8
Deciduous forest	3.7
Coniferous forest	13.8
Mixed forest	18.6
Vegetation	2.5
Water body	0.3
Sum	**100**

Figure 6 shows EC values measured by ihwb in the second half of the year 2017 in the Gersprenz main channel. The data over time give an impression about the dynamics during the measuring period. The values range from 140 µS/cm to 416 µS/cm (Wersau) with a mean value of 281 µS/cm (SD 73 µS/cm). For gauge Harreshausen, at the outlet of the basin, the measured values are between 274 µS/cm and 762 µS/cm, with a mean value of 574 µS/cm (SD 110 µS/cm). Again, there is a tendency of increasing EC values visible in downstream direction.

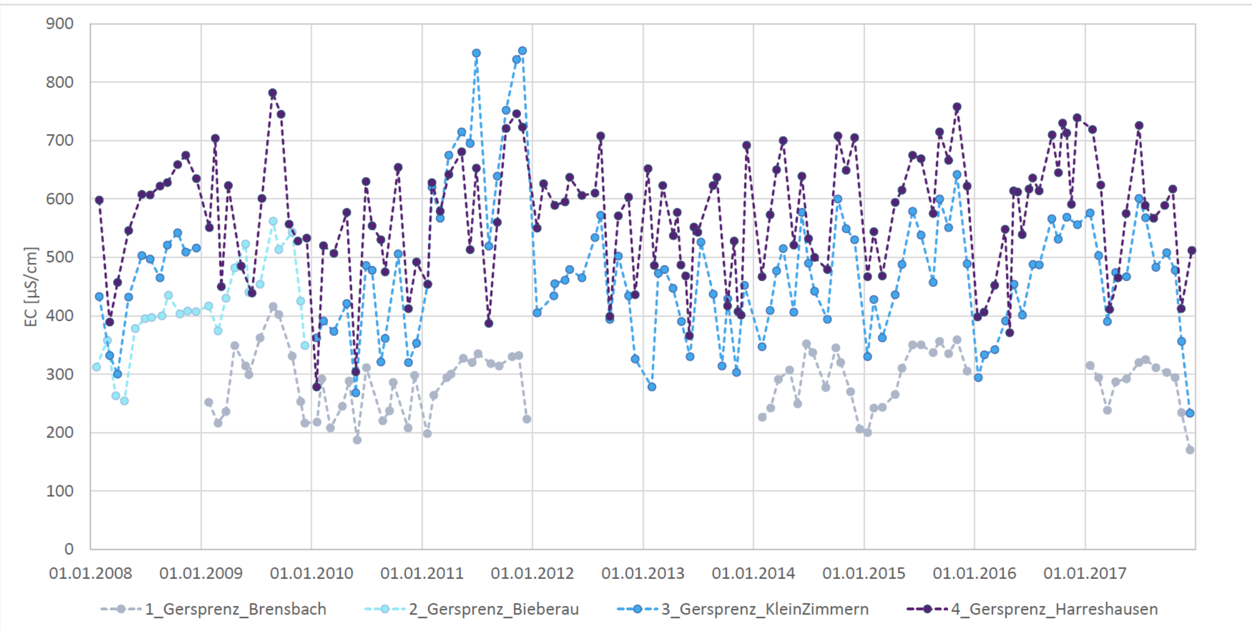

Figure 4: Monitoring results of the State of Hesse showing electrical conductivity (EC) values for the Gersprenz main stream (data source: HLNUG 2018a)

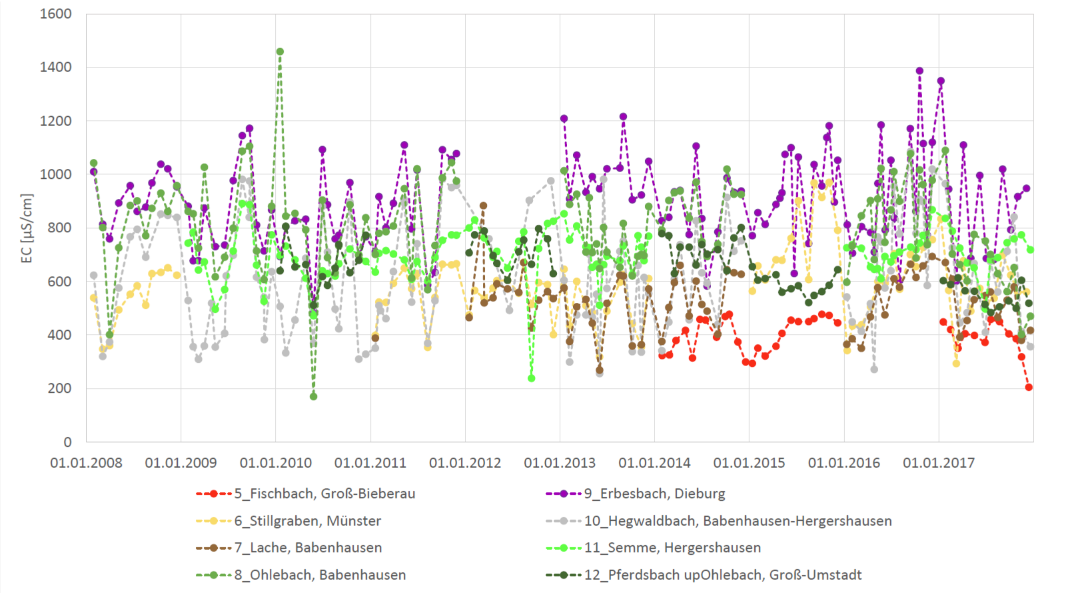

Figure 5: Monitoring results of the State of Hesse showing electrical conductivity (EC) values for the tributaries of the Gersprenz (data source: HLNUG, 2018a)

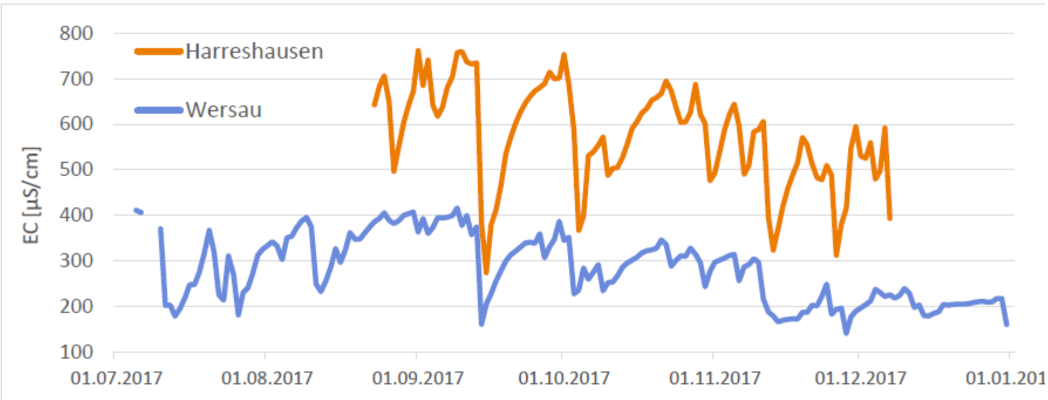

Figure 6: Monitoring results of the ihwb sensors showing electrical conductivity (EC) values for the gauges Wersau and Harreshausen in the Gersprenz river (Jul-Dec 2017, continuously measured)

4.2 Analysis of Fischbach subbasin

4.2.1 Land use

Due to the topography, the dominant land use in the Fischbach subbasin is mixed forest with only a very little share of coniferous forest and deciduous forest. Agriculture land is the second largest land use with 41.8% with equal shares of grassland and arable land (Figure 7, Table 4). Orchards are located in the transition outside of settlements. In comparison to the entire Gersprenz basin, the settlements are smaller. No wastewater treatment plants exist in this subbasin.

Table 4: Land use area in the Fischbach subbasin (data source: ATKIS®Basis-DLM 2017)

Land use class	% land use area
Settlement	6.5
Arable land	19.7
Orchard and tree nursery	2.4
Grassland	19.7
Deciduous forest	6.0
Coniferous forest	0.3
Mixed forest	44.1
Vegetation	1.3
Water bodies	0.1
Sum	**100**

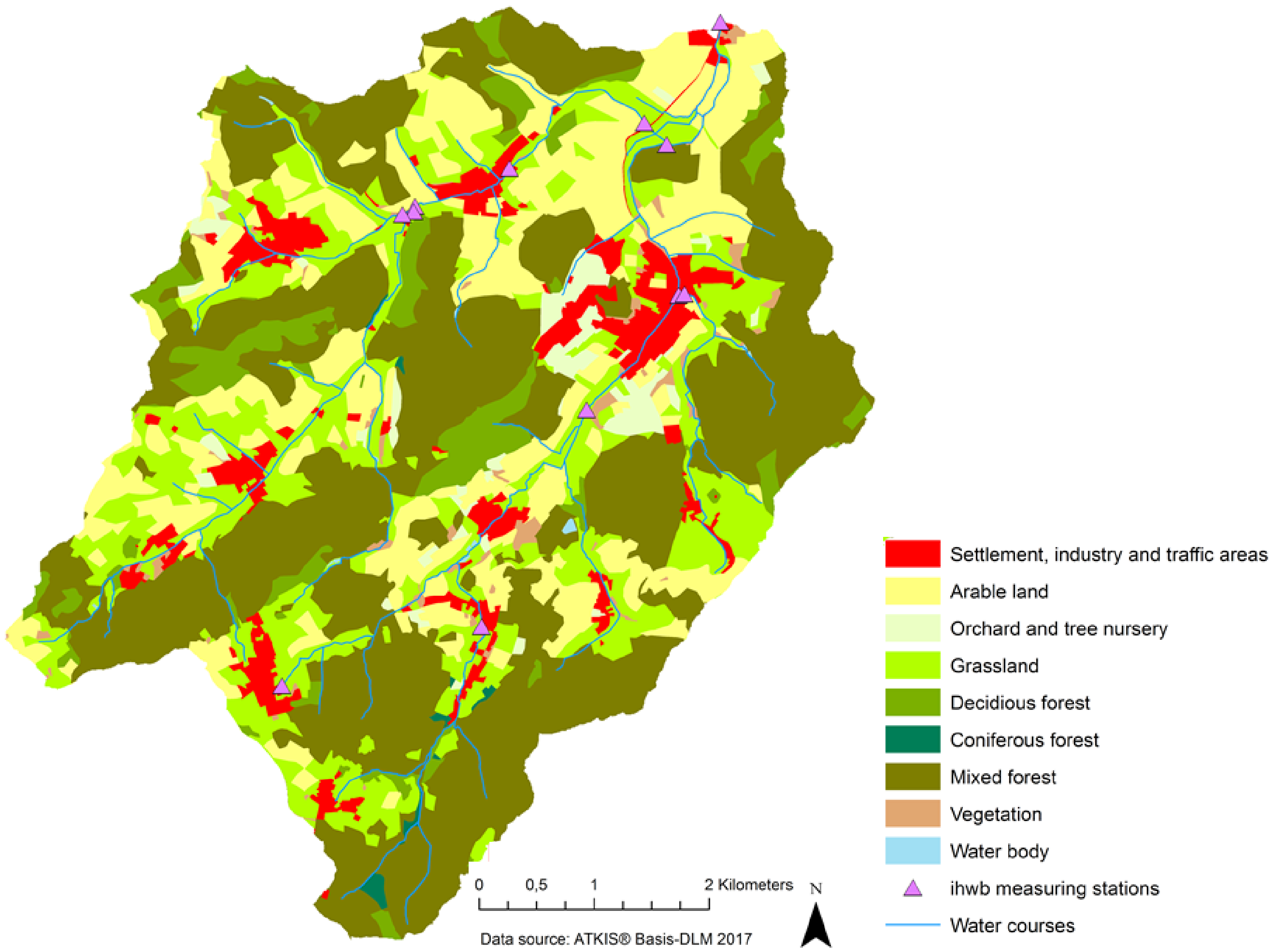

Figure 7: Water courses and land use in the Fischbach subbasin based on the ATKIS data set (data source: ATKIS®Basis-DLM 2017) and location of the sampling points from ihwb in the Fischbach subbasin

4.2.2 Hydrological data and studies

The spatially high-resolution monitoring EC data of the ihwb weekly campaign for the Fischbach subbasin in the year 2017 is between 124 µS/cm (D) and 456 µS/cm (Q) (Figure 8). The mean values of the 12 stations range from 201 µS/cm (D) to 413 µS/cm (Q).

The stream system Fischbach consists of two branches: The Fischbach –southeastern– and the Rodauer Bach –northwestern– (Figure 2). Whereas the EC values from the Fischbach and its tributaries with its stations A, D, E, F1 and F2 have mean values lower than 300 µS/cm, at the stations G, P, Q and PQ at the Rodauer Bach and its tributaries mean values >300 µS/cm (313-418 µS/cm) occur. Therefore, at the confluence of both branches, mean EC values of 311 µS/cm (O, Fischbach) and 367 µS/cm (N, Rodauer Bach) were analysed. Consequentially, the gauge Groß-Bieberau 2 (M) has a mean EC value of 359 µS/cm (Figure 8).

The monitoring data of the ihwb sensor for the gauge Groß-Bieberau 2 in the Fischbach stream (Jul-Dec 2017) covers EC values ranging from 174 µS/cm to 471 µS/cm with a mean value of 358 µS/cm. The water depths measured at the same time range from 17 to 80 cm (mean 28 cm) (Figure 9). A trend between EC and water levels can be determined: If the water levels increase caused by precipitation events, the EC values decrease. In summer, higher EC values and lower water levels, and in winter, lower EC values and higher water levels can be assumed.

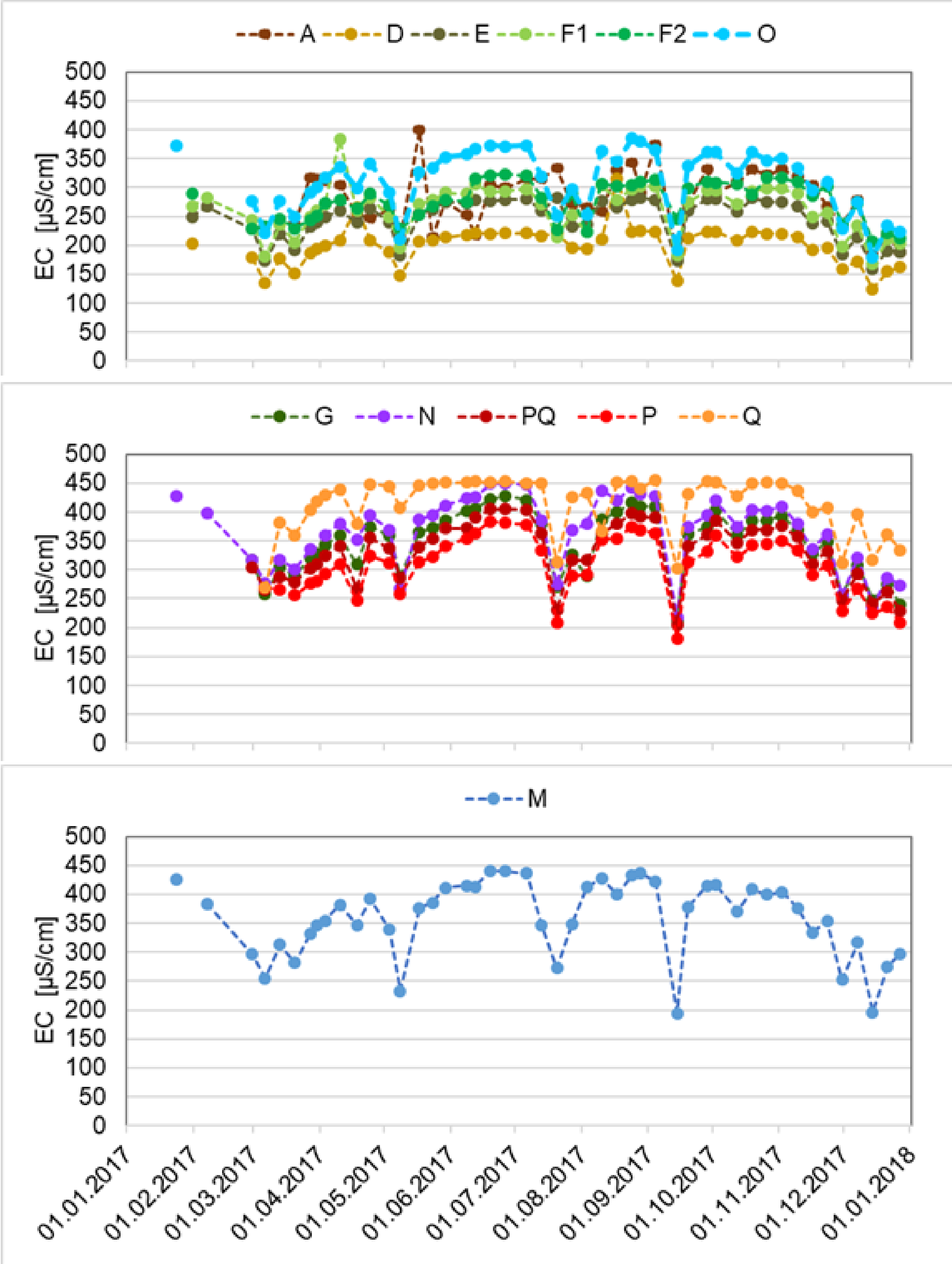

Figure 8: Monitoring results of the ihwb campaign showing electrical conductivity (EC) values for the Fischbach subbasin in the year 2017 (weekly resolution): Fischbach (upper chart), Rodauer Bach (middle chart), and gauge after confluence of the two branches (lower chart). Note: the same time scale was used.

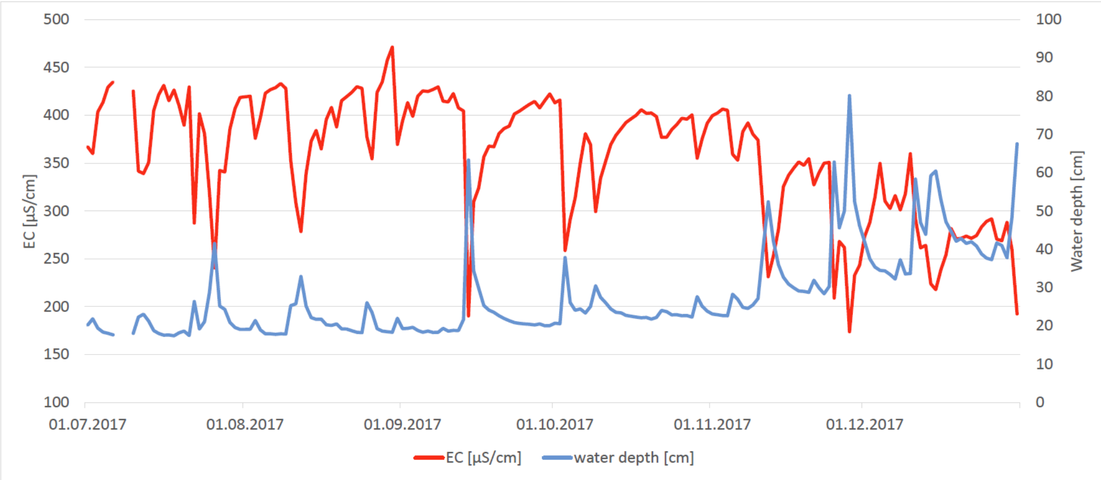

Figure 9: Monitoring results of the ihwb sensor showing electrical conductivity (EC) values and water depths for the gauge Groß-Bieberau 2 in the Fischbach stream (Jul-Dec 2017, continuously measured)

5 Discussion

5.1 Land use

Land use data is one of the most important data set for many hydrological studies and many ready-to-use products are available for Germany. The application of the ATKIS data set for both case study areas is suitable to compare both scales with the same input data. However, for detailed information on specific land use classes (e.g. crop (rotation), grassland management and forest conditions) additionally mapping is needed, which is very time-consuming for larger areas. The evaluation of statistical data (e.g. from the statistical office on agriculture) can give further information but is not always spatially explicit. Lüker-Jans et al. (2017) have analysed the interactions of changes in crop rotation due to the fostering of biogas plants in the previous years in Hesse and report a decreasing trend of arable land and permanent grassland from 2005-2010 of -0.9% respectively -1.4%. The effects on stream water quality should be analysed regarding such trends in land use management.

5.2 Hydrological data and studies

Stream typology (after EU WFD; EC 2000) for the Gersprenz river comprises a total of four "biocoenotically relevant stream types": three from the central highlands, and one "ecoregion independent" type (HLNUG 2018b). The stream types are described in form of stream type profiles including information about electrical conductivity values as exemplary character (Pottgiesser & Sommerhäuser 2008). The Gersprenz main stream comprises the type 5 (small coarse substrate dominated siliceous highland rivers) in the source region, type 9 (mid-sized fine to coarse substrate dominated siliceous highland rivers) further downstream, type 19 (small streams in riverine floodplains) in the lowland areas of the lower Main region. The tributaries are from types 6 (small fine substrate dominated calcareous highland rivers) and 19, but the Fischbach is type 5.

Low EC values are expected for the upstream Gersprenz main channel due to the classification in stream types 5 (50-300 µS/cm) and 9 (75-350 µS/cm; Pottgiesser & Sommerhäuser 2008). However, the observed values are within that expected range for 1_Gersprenz-Brensbach (mean of 287 µS/cm, HLNUG, 2018a, Figure 4), but not for 2_Gersprenz_ Bieberau which shows a higher mean value of 413 µS/cm (Figure 4).

For type 19, which is represented by stations 3_Gersprenz_Klein Zimmern and 4_Gersprenz_ Harreshausen, there is no EC value specified (Pottgiesser & Sommerhäuser, 2008).

Although the mean value of the tributaries is lowest in Fischbach (396 µS/cm; 2014-2015, 2017, HLNUG, 2018a), it is higher as expected for type 5 (50-300 S/cm, Pottgiesser & Sommerhäuser 2008). This is also confirmed by the ihwb measurements from Jul-Dec 2017 with an EC mean value of 359 µS/cm. Even though forest covers around 50% of the basin area (Table 4) and no communal waste water discharges into the streams, there are anthropogenic impacts on water quality by the small settlements including small enterprises and transport infrastructures as well as by the agricultural management of arable land (20% of basin area) and grassland (20%, Table 4).

5.3 Impact of land use on water quality

5.3.1 Gersprenz basin

The basin area is divided into three parts. The upstream part, which corresponds also to the area of the Vorderer Odenwald with its ow mountain range character, is characterised by a mosaic of different land uses on a small scale. Many grassland areas can be recognised. To the boundaries there are larger areas of mixed forest. Only a few settlements result in little anthropogenic impacts (Figure 3).

The central part of the basin area is dominated by arable land. There are several larger settlements and cities, for example Reinheim (ca. 16,000 inhabitants), Groß-Zimmern (ca. 14,000 inhabitants) and Groß-Umstadt (ca. 21,000 inhabitants). In addition to these settlement areas, commerce and industry as well as some wastewater treatment plants also lead to discharges into the rivers and streams.

From Dieburg downstream to the basin outlet there are three main characteristics: I) arable land mainly close to the Gersprenz river, II) coniferous and mixed forest mainly at the basin boundaries, and III) larger settlements and cities such as Dieburg, Münster or Babenhausen (each ca. 14,000-17,000 inhabitants). Commerce and industry are much more important, and numerous wastewater treatment plants are located here.

This increase in anthropogenic impacts from source to mouth (Figure 4), such as the increase in residential areas, commerce and industry as well as discharges, explains the increase in EC values, i.e. the deterioration in water quality. In addition, other tributaries, such as the Erbesbach (Figure 5), contribute with increased values.

Also other studies showed similar results. The results of Fučík et al. (2008) acquired from catchments in the Czech Republic showed that every 10% decrease of ploughed land proportion in a catchment lowers nutrient concentrations for a certain amount. The study of Covarrubia et al. (2016) shows that water quality is relatively good in the rural and agricultural region, shows signs of impairment in the residential region, and becomes heavily impaired in the industrial region.

5.3.2 Fischbach subbasin

Looking first at the northwestern branch of the stream, Rodauer Bach, two subbasins represent the headwater catchments (Figure 2, Figure 7): Asbach (with station Q) and Johannisbach (with station P). While around both stations are settlements as well as grassland along the stream, the subbasins are covered by a mixture of forest, arable land, grassland and settlements. The Johannisbach subbasin at station P has lower EC values (mean 307 µS/cm with a range from 181 to 384 µS/cm, SD 52 µS/cm) than the Asbach subbasin (station Q; mean 413 µS/cm with a range from 269 to 456 µS/cm, SD 50 µS/cm), possibly due to the close-by settlement of Asbach. These contents are mixed after the confluence forming the Rodauer Bach (station PQ with mean EC of 331 µS/cm, SD 53 µS/cm). Further downstream, after passing the settlement of Rodau, the EC values at station G have the same level (mean EC of 346 µS/cm, SD 56 µS/cm). Even further downstream with arable land and grassland along the stream, the mean EC value reaches 367 µS/cm at station N (minimum: 217 µS/cm, maximum: 450 µS/cm, SD 61 µS/cm) which represents the integral of the Rodauer Bach.

Secondly, analysing the southeastern branch of the stream, called Fischbach, in the source area around station A, settlement and grassland can be found (Figure 7). Mean EC was calculated as 283 µS/cm (min. 180 µS/cm, max. 400 µS/cm, SD 50 µS/cm, compare chapter 4.2.2).

Water at station D in the stream Steinbach has better quality: mean EC is 201 µS/cm (min. 124 µS/cm, max. 316 µS/cm, SD 34 µS/cm). Within this small subbasin mainly mixed forest and grassland occur, only the last kilometre along the stream a narrow strip is classified as settlement.

The upstream section from A to E is characterised by a mosaic of different land uses, and close to the station E by grassland along the stream with arable land in the vicinity. Water quality relating to EC is slightly better (mean 246 µS/cm, SD 35 µS/cm) than at the source station A.

Further downstream, from E to F1, settlement has again only a slight negative impact on EC (mean 263 µS/cm, SD 42 µS/cm). The tributary F2 that discharges within that area has only a slight effect on the water quality (mean 276 µS/cm, SD 34 µS/cm). Its small subbasin is covered by settlement, and upstream by mixed forest.

The station O can be described as an integral of the southeastern Fischbach subbasin. The mean EC is highest along the stream with 311 µS/cm (SD 55 µS/cm).

Finally, the station M corresponds to the total integral of the total Fischbach basin. The resulting mean EC value of 359 µS/cm (SD 65 µS/cm) can be explained by all influencing factors within the river basin such as different land use, water discharge, etc. However, as forest covers around 50% of the basin area (Table 4), no communal waste water discharges into the streams and only 6.5% is characterised by settlements, industry and traffic, the possible influence of pollution is small.

5.4 Data quality and approach

5.4.1 Land use

The official ATKIS land use data is of high accuracy regarding the location of the individual classes and the data set is updated regularly. Only regarding the thematic resolution of the agricultural classes the data set reveals some disadvantages. For a more detailed assessment of the influence of specific crops or management options, additional data has to be added. High accuracy data regarding spatial and temporal resolution is only limited available, especially for larger study areas.

5.4.2 Hydrological data

With regard to the data quality and resolution of the hydrological data, the following can be stated: The EC values considered were measured in different spatial and temporal resolutions.

The analysed data for the entire Gersprenz basin (HLNUG) correspond to the data collection in a state-wide monitoring network. However, water monitoring only takes place periodically, usually monthly, so this method only provides a snapshot of water quality status.

The weekly measured values by ihwb have a higher temporal resolution, but still represent only a random sampling, since the dynamics during the intervening period cannot be depicted. For a smaller basin area such as the Fischbach, the effort for this type of reference dates can be carried out on a weekly basis, but larger areas are not covered by this method.

Continuous sampling offers the advantage of high-resolution monitoring. However, it can only be carried out at few selected locations. However, the time series allows a complete recording of data, also including water level and/or discharge data. This evaluation is a useful supplement to the land use analysis. Also Petersen et al. (2017) observed in two rivers in South Africa that EC followed the trends of the rainfall and flows recorded in the catchment, resulting in a negative correlation with river flows. Increases of EC values coincided with very low river flow years or drought periods.

The introduced analysis on two scales by two different institutions enables an attribution of the ihwb measurements into the overall context of state-wide sampling and provides a valuable source of information for the understanding of hydrological processes and their impacts and variability.

6 Conclusions and Outlook

The depiction of the current river quality status and the understanding of hydrological processes are one of the key aims of the here presented field laboratory. Therefore, in this study the characteristics of the Gersprenz basin in the German low mountain range area were depicted as a representative study area for the German low mountain range. The current river quality status - using electrical conductivity (EC) as a possible indicator - was analysed and assessed concerning the interplay between hydrology and land use. The impact of land use on hydrology was examined by relating water quality to land use pattern (i.e. agricultural areas, settlements including industry, commerce areas and traffic, discharge of waste water), as well as water level dynamics due to precipitation events. Own monitoring, conducted by ihwb at TU Darmstadt, complements the state-wide monitoring (HLNUG) and is a valuable combination of spatial coverage and methodological approach. Intensive monitoring with a denser monitoring network is easier in smaller basins.

The results show that water quality, using EC as an indicator, can be related to land use pattern. From stream source to mouth, there is an increase in anthropogenic impacts. Land use in the entire Gersprenz basin is dominated by agriculture (ca. 48%), followed by forest (ca. 36%). The upstream part has a low mountain range character and is characterised by a mosaic of different smaller land use areas. The central part of the basin area is dominated by arable land, but also several larger settlements including commerce and industry occur. Further downstream, arable land, forest and larger settlements coexist. In the Fischbach subbasin, there is more forest (ca. 50%) than agriculture (ca. 42%).

The analysed EC values show an increasing tendency in downstream direction in the Gersprenz main channel and in the Fischbach stream system. The tributaries contribute very differently to the deterioration of water quality of the main stream.

A clear relationship between EC and water levels can be determined with decreasing EC values at increasing water levels caused by precipitation events.

The influence of land use in the basin area is visible in the results. However, due to the size of the analysed subbasins and the heterogeneity of land use, no clear correlation can be made. The sampling points always correspond to a mixed signal from the upstream area. Therefore, the increasing anthropogenic influence towards the lower reaches is also reflected in rising EC values. This anthropogenic impact is due to agricultural use, settlements, commerce and industry, and discharges of waste water. These patterns are clearly visible on the mesoscale. For more detailed, high resolution observations, these relationships are more distinct, but then also require time series with higher temporal and spatial resolution which are not available yet.

This initial study in this new case study area (ihwb field observatory) will be continued in the future. Further research topics of high relevance for the case study area are, e.g. soil erosion, sediment transport, low flow, effects of heavy rain events and analysis of additional water quality parameters. Further measuring stations and particularly the recording of continuously measured data are to be added. Land use should also be mapped in more detail to further differentiate agricultural use, e.g. into different crops, which is important for the methodological development of the further research topics.

Future land and water management should be coordinated between all stakeholders and be based on comprehensive scientific knowledge and the awareness about the interactions between landscape characteristics and hydrology.

List of abbreviations

- EC: electrical conductivity
- HLNUG: Hessisches Landesamt für Naturschutz, Umwelt und Geologie (Hessian Agency for Nature Conservation, Environment and Geology)
- ihwb: Chair of Engineering Hydrology and Water Management, Technische Universität Darmstadt

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