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Ecological, socio-economic and demographic analyses as prerequisites for sewage treatment problem solutions in rural areas. The case study of Dirlammen, Vogelsberg, Germany

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Abstract

The municipal sewage treatment in Germany is traditionally centralized and allows for a high disposal security. The implementation of the EU Water Framework Directive (EU-WFD) showed that the central target, the so-called 'good ecological state' has not yet been reached in 90% of all surface water bodies. A common and widespread measure to reach said target is the improvement of sewage treatment plants (STP). A large part of the expenses for that has to be shouldered by local communities. But many rural communities already have to manage high costs caused by the modernization of the sewage pipe system. And as the size of the rural population decreases continuously, the per capita burden increases. This raises the question whether the construction of a new sewage treatment plant is the most efficient way to improve the water quality in rural areas. A comprehensive approach has been developed for answering this question, consisting of 1) biological and physico-chemical wastewater analyses, 2) a modified eco-balance for the construction of a new STP and 3) socio-economic and demographic population analyses. The results show that the water quality of the studied creek is good with exception of the sewage disposal point. The eco-balance for the construction, the operation, and the environmental side effects show that the continued operation of the existing STP is more effective than the construction of a modern facility. This conclusion is supported by the aging and general decrease of the rural population. The diminishing potential to shoulder additional costs is in contrast to the reduced future demand for a modern STP.

Zusammenfassung

Die kommunale Abwasserbehandlung erfolgt in Deutschland traditionell zentralisiert. Das garantiert eine hohe Entsorgungssicherheit. Die Implementierung der EU-Wasserrahmenrichtlinie (EU-WRRL) hat gezeigt, dass das Hauptziel, der „gute ökologische Zustand", in den meisten Oberflächenwasserkörpern (90%) noch nicht erreicht wurde. Eine weitverbreitete Maßnahme, den ökologischen Zustand von Fließgewässern zu verbessern, ist die Modernisierung der Abwasserreinigungsanlagen. Ein Großteil der Kosten für diese Maßnahmen wird dabei von

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den Kommunen getragen. Gleichzeitig finanzieren die ländlichen Gemeinden die teure Modernisierung des Abwasserleitungssystems, während die Bevölkerungszahl in vielen ländlichen Gemeinden kontinuierlich abnimmt. Deshalb bestand die zentrale Zielstellung dieser Studie darin, herauszufinden, ob der Bau einer neuen Abwasserreinigungsanlage der effizienteste Weg ist, die Wasserqualität im ländlichen Raum zu verbessern. Hierfür wurde im Untersuchungsgebiet ein integrierter Untersuchungsansatz bestehend aus: 1) einer biologischen und physikochemischen Abwasseranalyse, 2) einer modifizierten Öko-Bilanz für den Bau einer neuen Abwasserreinigungsanlage sowie 3) einer sozio-ökonomischen und demographischen Bevölkerungsanalyse verfolgt. Die Abwasseranalysen ergaben, dass die Wasserqualität im Fließgewässer mit Ausnahme des Abwassereinleitungsabschnitts gut ist. Die Ergebnisse der Öko-Bilanz unter Einbeziehung der Bau- und Unterhaltungskosten sowie der Umweltnebenwirkungen zeigten, dass der Weiterbetrieb der existierenden Abwasserreinigungsanlage effizienter ist als der Bau einer neuen Anlage. Dieser Schluss wird auch durch die Überalterung und den Bevölkerungsrückgang in der Gemeinde gestützt. Das schwindende Potential, zusätzliche Kosten zu schultern, steht im Gegensatz zu dem in Zukunft sinkenden Bedarf für eine moderne Abwasserbehandlungsanlage.

Keywords sewage treatment, rural areas, ecological analysis, eco-balance, demographic analysis

1. Introduction

The Water Framework Directive of the European Union (EU-WFD), which was ratified in the year 2000, is a tool to improve the water quality. The main target for all surface and groundwater bodies is the so-called ‘good ecological state’ until 2015 (and by prolongation until 2027) (*EU* 2000). The EU-WFD defines the ‘good ecological status’ as the combination of chemical quality conditions (defined by standards for the maximum concentrations of specific water pollutants) and biological quality conditions (assessed via indicator species such as fish, benthic invertebrates, or macrophytes in combination with physico-chemical quality conditions like temperature, oxygen, and nutrient concentrations). While the non-point impacts on water bodies are extremely difficult to monitor, the effects of point sources are much easier to assess. Therefore, the many activities aimed at the improvement of the water quality are directed towards the reduction of the harmful pollutants from these point sources (*Bruch* 2002). The construction and operation of sewage treatment plants (STP) in combination with issuing and enforcing wastewater quality standards and pollutant thresholds has led to a considerable improvement of the water quality in the EU countries since the 1960s (*Kessler* 2004).

The German municipal sewage treatment system is characterized by a high degree of centralization (*Seeger* 1999) and provides a reliable disposal security (*GWP* 2009). Studies conducted in the 1990s also showed that any further improvement of the water quality would require huge financial costs. An alternative and more affordable way to improve the water quality of rivers and creeks is the enhancement of the self-purification potential, which is a beneficial side effect of river restoration measures (*Diehl* 2004; *Groll* and *Opp* 2007). Due to their smaller catchment areas and smaller length, creeks possess an only limited ability for self-purification and dilution of pollutants. Settlements in the upper catchments usually solely have access to pond sewage plants with a reduced purification capacity. These pond sewage treatment plants are based on microbial self-purification processes and are, due to their cost-effectiveness, the most common wastewater treatment technology in less densely populated rural areas in Germany (*Borchard* and *Menadi* 2001; *LfU* 2006). But at the same time, the purification result in the pond sewage treatment plants is limited. According to the German wastewater ordinance (*AbwV 2004*), which defines the purification requirements based on state of the art technologies for wastewater disposal in dependence on the population equivalent, the ventilated pond sewage plant in Dirlammen meets the requirements of level 1 (up to 1,000 population equivalents) and level 2 (up to 5,000 population equivalents) (c.f. *Photos 1* and *2*). While this means that this simple purification technique is suitable enough for the carbon depletion (CSB, BSB5), the Dirlammen STP is not equipped to facilitate direct nitrification and fertilizer elimination. Therefore, the discharged treated water still contains residues of various pollutants and contributes to the impairment of the water quality of rivers and streams downstream. In order to solve this problem, the construction of modern sewage treatment plants is a popular demand of many politicians and environmentalists. Due to the smaller size of many rural communities and the often larger distances to the next STP, the rural population often has already to pay above average per capita fees for the maintenance and operation of these wastewater treatment facilities and for the rehabilitation of the household's sewage pipe system. In the Vogelsberg district, for instance, the average wastewater fee is 4.81 €/m^3 (excluding additional costs for the rehabilitation of the pipe system) while the average fee in the rural Lautertal municipality (in the Vogelsberg district) is 6.00 €/m^3 (*RPGI* 2017). The construction of new STPs would add an additional financial burden onto the rural population, which seems unreasonable, especially as the size and density of the population in rural areas has been decreasing for decades and will continue to do so in the future (*HSL* 2007-2012; *BBSR* 2017). Therefore, the investments for the construction of new sewage treatment plants cannot be covered by the rural communities and alternative solutions are needed.

Photo 1 and 2
The rural area of the municipality Lautertal (top) and the community of Dirlammen (bottom) within the Vogelsberg District, Federal State of Hesse, Germany. Photo credit above: B. Ziebolz 2016, photo credit below: aerial photo, Ziebolz 2016: 3 (unpublished), based on Renker 2005

2. Study area

The problem outlined above is typical for the community of Dirlammen within the municipality of Lautertal in the Vogelsberg district of the federal state of Hesse (*Photos 1* and *2*). Lautertal has a population of 2,424 and a population density of 45 inhabitants per km^2. Dirlammen itself has a present (2017) population of 381 within 140 households, each of them with an average of two toilets. The population dynamics (1970: 425, 2007: 413, 2012: 404, 2013: 391, 2014: 389, 2015: 390, 2016: 392) show a falling tendency. The community members use on average 35-40 m^3 freshwater (and wastewater) per inhabitant. Dirlammen is located at 453 m a.s.l. and covers an area of 53.61 km^2 (*HSL* 2012). Since 1987, the municipality of Lautertal operates an oxygenated pond sewage plant in Dirlammen. The community has invested 287,000 Euro for the construction and operation of the present STP, which has not been upgraded since construction. Among the total of 707 STPs in the Federal State of Hesse, 133 belong to this type (*DWA* 2016). It consists of two connected oxygenated wastewater ponds and one maturation pond with a shallow water zone for treating the mixed domestic wastewater and storm water (*Photo 3*). Both oxygenated wastewater ponds have a water depth of 2.50 m and a combined surface area of 896.5 m^2 (*Photo 4*). The maturation pond has a depth of one meter and a surface area of 360 m^2 (*Photo 5*).

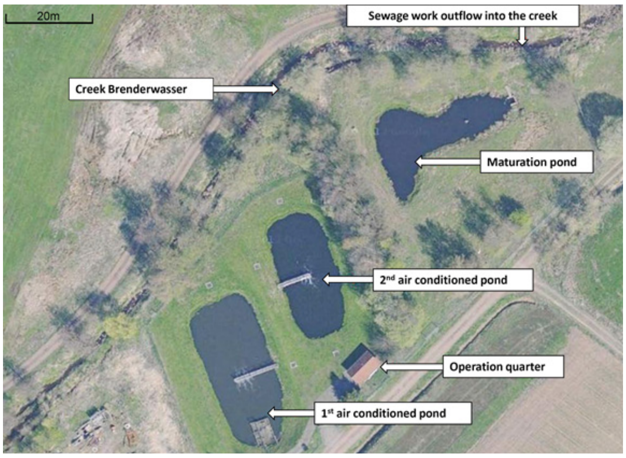

Photo 3 Pond sewage plant in Dirlammen. Source: Own elaboration, based on Google Maps 2013

Photo 4 First and second air conditioned pond of the pond sewage plant in Dirlammen. Photo credit: C. Opp 2017

Photo 5 The maturation pond of the pond sewage plant in Dirlammen with algae growing during July. Photo credit: C. Opp 2017

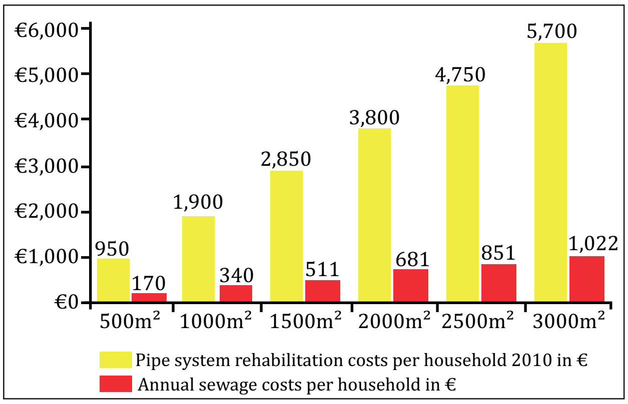

Fig. 1 Additional sewage costs per household for the rehabilitation of the sewage pipe system 2010 (yellow) and annual sewage costs (red) in dependence of the plot area. Source: Own elaboration, based on community information

The wastewater treatment technology used in the Dirlammen STP is based on the principles of biological self-purification in water bodies (*Röske* and *Uhlmann* 2005). Like in natural water bodies, bacteria consuming oxygen desintegrate the easily biodegradable organic components of the raw sewage. The growing bacteria biomass utilizes the biochemical energy and transforms it into mineralized products of the biodegradation (water, carbon dioxide, ammonium, phosphate), which, in turn, form the basis for the photosynthetically active phytoplankton. The oxygen produced by the plankton is then used by bacteria. A large part of the excess mass of bacteria and algae is consumed by zooplankton (especially *Daphnia* sp.), which causes a substantial purification effect (*Röske* and *Uhlmann* 2005). Due to the limitations of this process, nitrification, denitrification, and phosphorus elimination cannot be achieved by the Dirlammen STP.

Independent water quality measuring campaigns in the Brenderwasser Creek during the past years have revealed high ammonia loads with a clear exceedance of the corresponding threshold. Also, the sampled macrozoobenthos species indicated an impaired water quality. Both of these deficits were detected downstream of the sewage disposal point, while the water quality recovered gradually with a greater distance from the wastewater inflow. The lowest water quality values in the Brenderwasser were detected during low water periods, when dilution processes are severely limited (*RP Gießen* 2008). This point source pollution put plans for a replacement of the old pond sewage plant with a new sewage treatment facility on the agenda. But both the community of Dirlammen and the municipality of Lautertal lack the financial means for such an investment. Furthermore, the local population has already had to contribute to the rehabilitation of the sewage pipe system on top of the regular sewage costs (*Fig. 1*), making any additional financial burden infeasible.

Overall, the construction of a new STP would not be affordable by the municipality, the community, and the local population, while such a modern STP could not operate at full capacity, given the continuously decreasing population. Hence, a modern STP would not fulfill the cost-efficiency requirement of the EU-WFD.

3. Objectives, approach, and methods

Based on these problems, multiple research questions, objectives, and methods were selected for this case study. Due to the fact that the water quality data had been collected several years before this study was conducted, it was necessary to assess the present status quo of the creek's pollution caused by the pond sewage plant Dirlammen. The first step in this regard was a preliminary analysis of the water body characteristics, especially the river type based on *Pottgiesser* and *Sommerhäuser* (2008), the riverbed structures based on *Groll* and *Opp* (2007), *Groll* et al. (2016), and *Groll* (2017). This was followed by the assessment of the saprobic indicator species of the macrozoobenthos (after *Klee* 1998 and *Meier* 2006). The faunistic sampling and the taxonomic determination of the macrozoobenthos were conducted in accordance with the updated guidelines for the assessment of the saprobic index (*DIN* 2004). This biological and physico-chemical monitoring of the creek's water was carried out at four sampling points in different distances from the sewage disposal point, analyzing the spatial extent of the wastewater influence. The monitoring was conducted four times during spring (22 March, 26 April) and summer (21 June, 12 July) of 2010 during varying seasonal water level and discharge conditions of the Brenderwasser Creek, analyzing the influence of the hydrology on the water quality. Continuous measurements were not possible because of partly strong fluctuations within the low water segment of the little creek. With the help of this multi-temporal and spatially differentiated water quality monitoring, it became possible to evaluate the impact of the pond sewage plant Dirlammen on the status quo of the Brenderwasser Creek (*Fig. 2*).

The four sampling points (SP) along the Brenderwasser Creek were located near the settlement of Dirlammen, with SP1 being 200 m upstream of the STP outlet, SP2 being located directly 50 m downstream of the STP outlet, followed by SP3 and SP4, which were located 900 and 2,200 m downstream of the STP outlet.

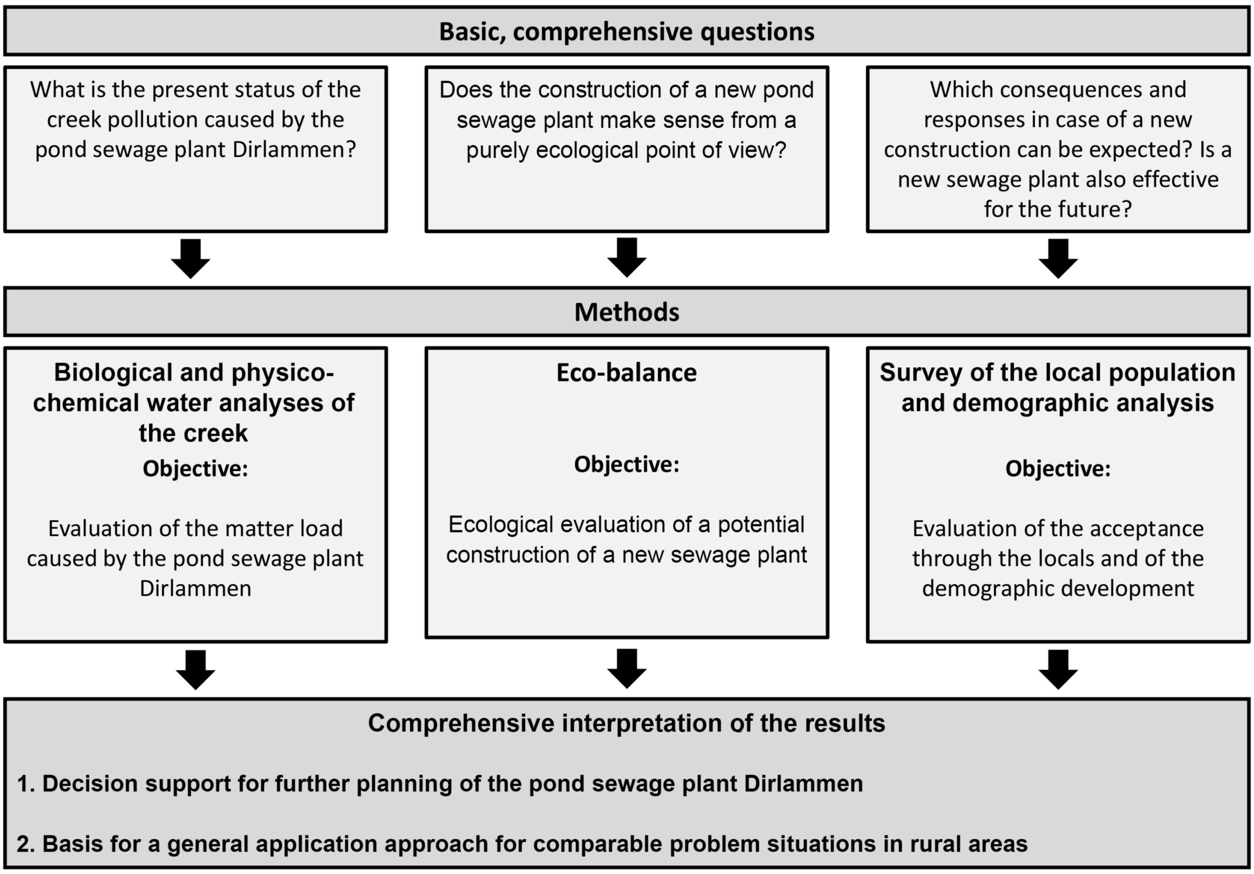

Fig. 2 Research approach (questions, methods, and objectives). Source: Own elaboration

The water quality monitoring program carried out at each of these four sampling points included the following parameters: water temperature (°C), pH-value, electric conductivity (EC, µS/cm), oxygen concentration (mg/l) and saturation (%) as well as the concentration of various nutrients (NH_3, NH_4, NO_2, NO_3, total phosphorus), all of which were analyzed on site using a WTW multi-parameter field kit (*WTW* 2016) and following the federal water agreement regulations (*LAWA-AO* 2007). In addition to these parameters, the discharge (l/s) was determined at spillways next to the SPs using the Poleni formula (*Bollrich* 2007).

Discharge and water temperature influence the solubility of various pollutants and, thus, control the self-purification processes of the creek. The pH value controls the abundance and vitality of the benthic organisms, which in turn influence the decomposition of organic material and in consequence the self-purification processes. The electric conductivity (EC), as an indicator of the total ion concentration, is a measure of the pollution influx from the STP. The nitrogen, phosphorus and oxygen values are used for the evaluation of the effectiveness of the self-purification processes along the creek.

In order to assess the viability of the construction of a new STP versus the continued operation of the old one, an eco-balance (or life cycle assessment) based on the studies of *Klöpfer* and *Grahl* (2009) was developed. A simple life cycle includes the following steps: the primary raw material and energy production, the semi-finished production, the final production, the usage, and the clearance respectively reclamation as well as all transport impacts between these steps (*IINAS* 2018). With the help of the eco-balance, it is possible to detect the environmental impacts caused by the production, technologies, and services utilized by any project (*Schmitz* and *Paulini* 1999). An eco-balance according to *EN ISO 14044* (2006) is comprised of the following components: 1) determination of the objective(s) and the framework, 2) balance of substances, 3) evaluation of the effects and 4) assessment. In this case, the eco-balance contains the determination of the production costs of a new STP, including the material costs, and the costs for the operation. Details of the used methods 2), 3) and 4) are described by *Schubert* (2006). Furthermore, the eco-balance according to *Klöpfer* and *Grahl* (2009) includes the comparison and evaluation of additional environmental side effects, such as the greenhouse effect (with a very high ecological priority), the summer smog and acidification (both with a high ecological priority) as well as the energy demand and direct disturbances of the aquatic ecosystem (with a moderate ecological priority). All of these parameters have been analyzed for a potential new STP and for the existing pond sewage treatment plant. In both cases, scenarios for operating times of 15 and 30 years have been analysed.

These analyses and evaluations were carried out with the help of the computer software GEMIS (Global Emission Model Integrated System), version 4.5 (*IINAS* 2018). The GEMIS database for this study contains information about: the allocation of energy sources, the thermal and electric power, building materials, and transport processes. For example, the emissions of greenhouse gases and the utilization of resources were determined pro rata for the production and the operation of a chain dredger and a lorry, for the production of cement flagging, and screed or for the mining and production of sand, split, gravel, basaltic crushed sand, bricks, and polyethylene pips. GEMIS calculates so-called life cycles for all processes and scenarios. For all these processes, the database specified the degrees of efficiency and utilization, the output and life time, the direct airborne pollutants, the greenhouse gas emissions as well as the solid and liquid residual materials. With the help of GEMIS, the assessment of environmental analyses, for example the aggregation of resources in form of a cumulated energy demand or of harmful substances for the climate became possible (*IINAS* 2018).

The final step of the study design was the development of socio-economic questionnaires in accordance to *Schnell* (1999) and interviews with the local inhabitants, which were carried out for the assessment of the age-related and employment-related population structure as well as for the monetary potential of the locals to pay for higher wastewater treatment costs (*Fig. 1*).

4. Results

4.1 Physico-chemical and biological analyses

The Brenderwasser Creek is a type 5 river ("small river of the lower mountain range"; *Döbbelt-Grüne* et al. 2014: 78). Rivers of this type are characterized by coarse, silicate sediments. This was confirmed by the riverbed analysis, which revealed a clear dominance of coarse gravel and pebbles at nearly all sampling

points, while organic materials were detected in only small quantities (< 5%). The sampling point nearby the STP outlet (SP2) showed a significantly higher amount of organic material (covering 15% of the riverbed), which coincided with the dominance of *Asselus aquaticus*, a faunistic indicator for bad to mediocre water quality. All the other sampling sites were characterized by species indicating a good water quality (quality class 2; saprobic index of 1.79-1.90, cf. *Fig. 3*).
The discharge and temperature dynamics reflect characteristic seasonal changes (*Fig. 4*). While the pH-values (7.2-8.4) did not fluctuate very much over time, the electric conductivity (EC) showed a steady increase from March to July. The highest overall EC values were detected at SP2, near the inflow of the treated wastewater. There, the EC ranged between 170 and 240 µS/cm in March, April, and June and reached 730 µS/cm in July. 2,200 m downstream (SP4) of the STP, the electric conductivity in July was considerably lower (375 µS/cm). Although the discharge in July was very low and the water temperature was high (cf. *Fig. 4*), the Brenderwasser Creek was able to dilute the ion load coming from the STP point source. The lowest EC values were measured at SP1 (upstream the STP outlet) during all times. The electric conductivity in March, April, and June was around 150 µS/cm, while in July it was 350 µS/cm.

The strong impact of the STP on the Brenderwasser Creek was also detected in the NH_3-N (*Fig. 4*) and NH_4-N concentrations. Both nitrogen concentrations showed the same distribution pattern with the lowest concentrations recorded at SP1, the maximum at SP2, followed by a gradual decrease of the concentration towards SP4. Phosphorus also showed the highest concentrations throughout the year at SP2 with strong fluctuations between 0.3-0.6 mg/l from March to June and a very high concentration of 3.2 mg/l during the low-flow situation in July. This is a consequence of the reduced dilution capacity during periods of very low discharge (*Photo 6*). Furthermore, the oxygen concentration and saturation reached their minimum values at SP2, near the STP outflow. The highest oxygen concentrations were detected in March (12.0 mg/l and 100%) while the minima were registered in July.

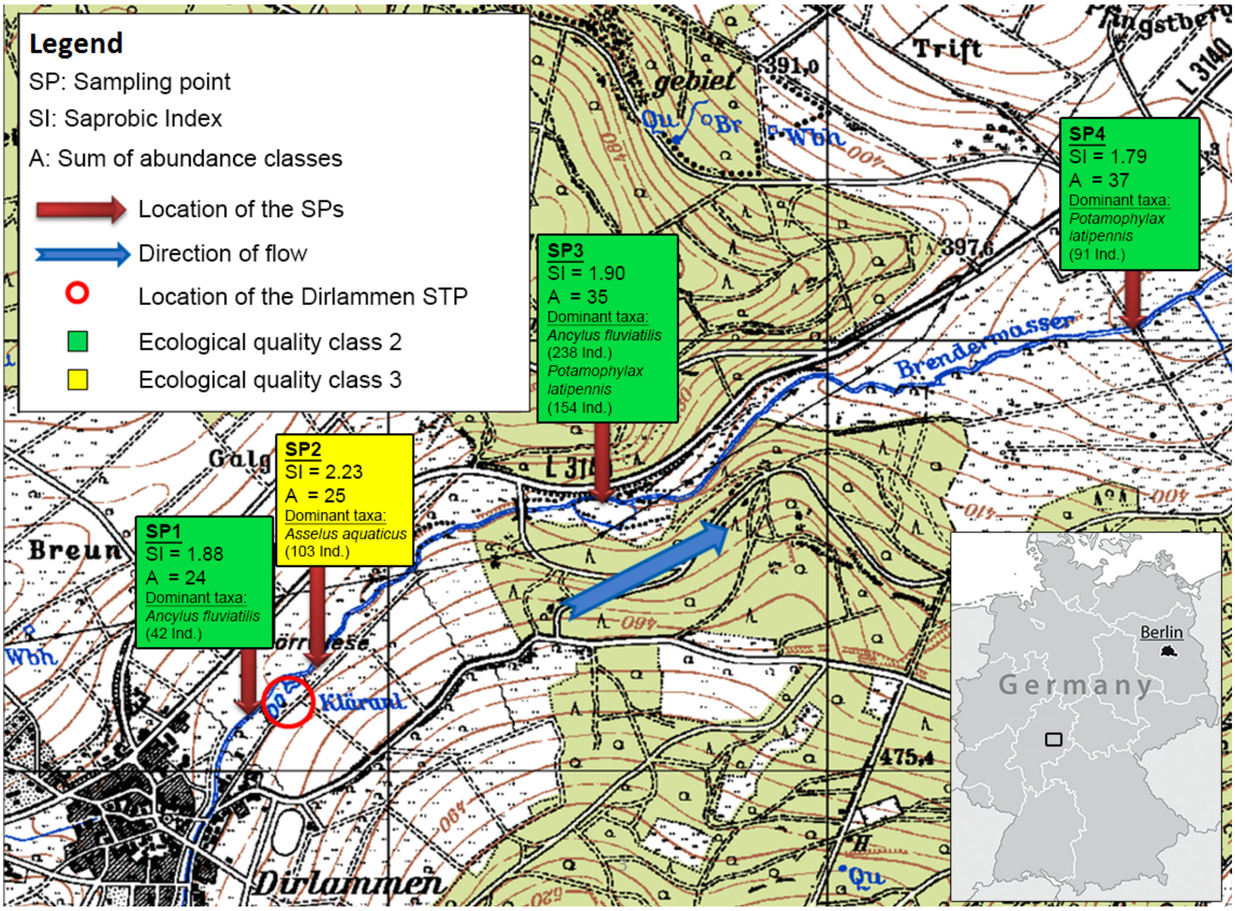

Fig. 3 Saprobic Index (SI), species abundance classes (A), ecological quality classes, and macrozoobenthos dominance along the sampling points (SP1-SP4) in the Brenderwasser Creek near Dirlammen. Source: Own elaboration, based on HVBG 2017

Dataset	◆ (blue)	■ (green)	▲ (yellow)	● (red)
Date	22/03/2010	26/04/2010	21/06/2010	12/07/2010
Discharge (l/s)	668	9	5	1
Ø Water temp. (°C)	7.3	15.2	12.4	19.9

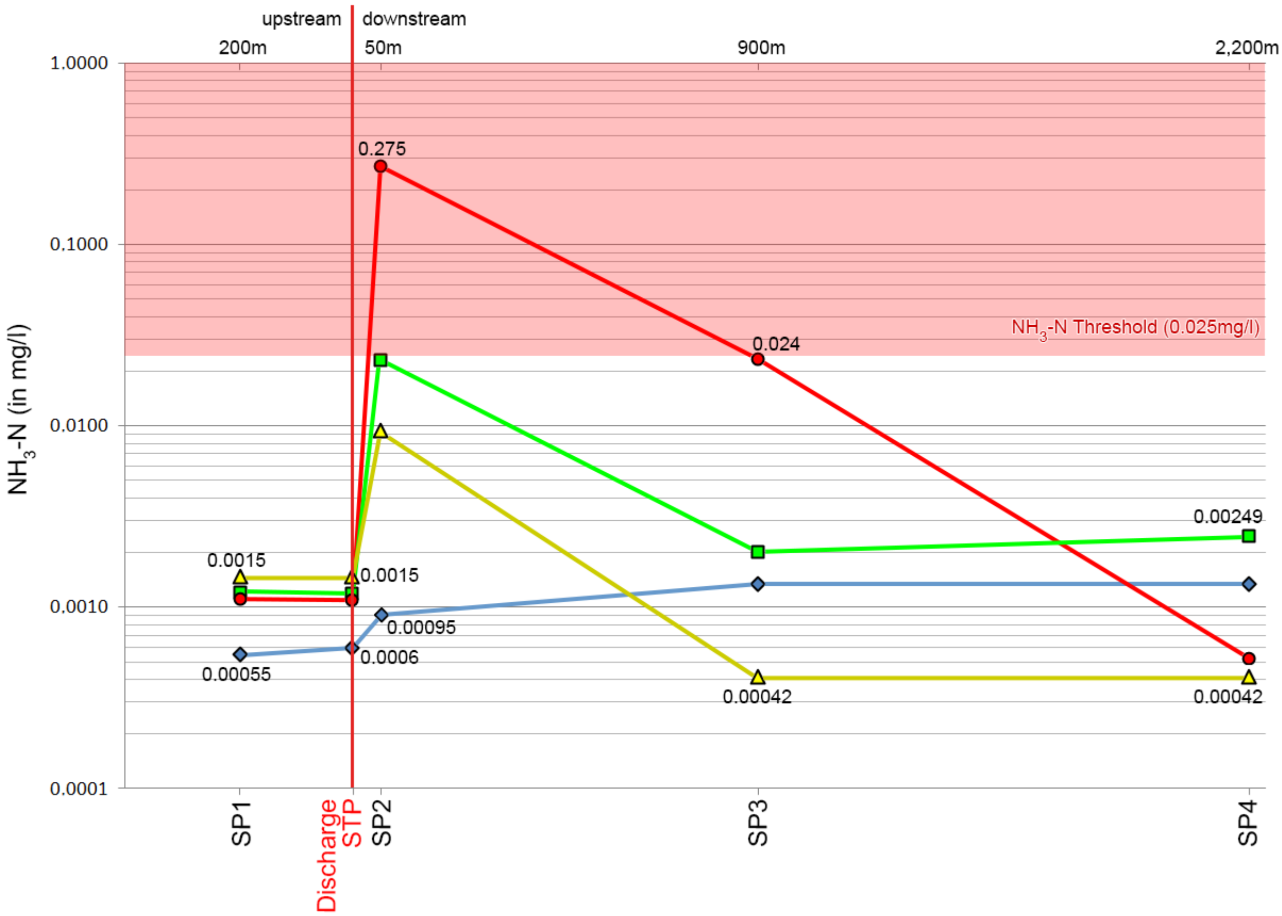

Fig. 4 Ammonia concentration at the four sampling sites during four measuring times along the Brenderwasser Creek near Dirlammen (SP2 50 m downstream of the sewage treatment plant). Source: Own elaboration

Photo 6 Low discharge of the Brenderwasser Creek in July 2017. Photo credit: C. Opp 2017

4.2 Eco-balance (life cycle assessment)

The eco-balance approach used in this study was based on a comparison of the operation of the existing pond STP Dirlammen with the construction and operation of a new sewage treatment plant. The BIOCOS (*Biological Combined System* 2004) STP in Wahlen (*Fig. 5*) represents an already existing modern STP. Because of its size (575 population equivalent) and the novel process technology, the BIOCOS sewage treatment plant in Wahlen (part of the municipality of Kirtorf, Federal State of Hesse, Germany) is well suited as a comparable example for the potential new sewage plant in Dirlammen. Therefore, all necessary data for the eco-balance of the Dirlammen STP have been extracted from the BIOCOS STP in Wahlen.

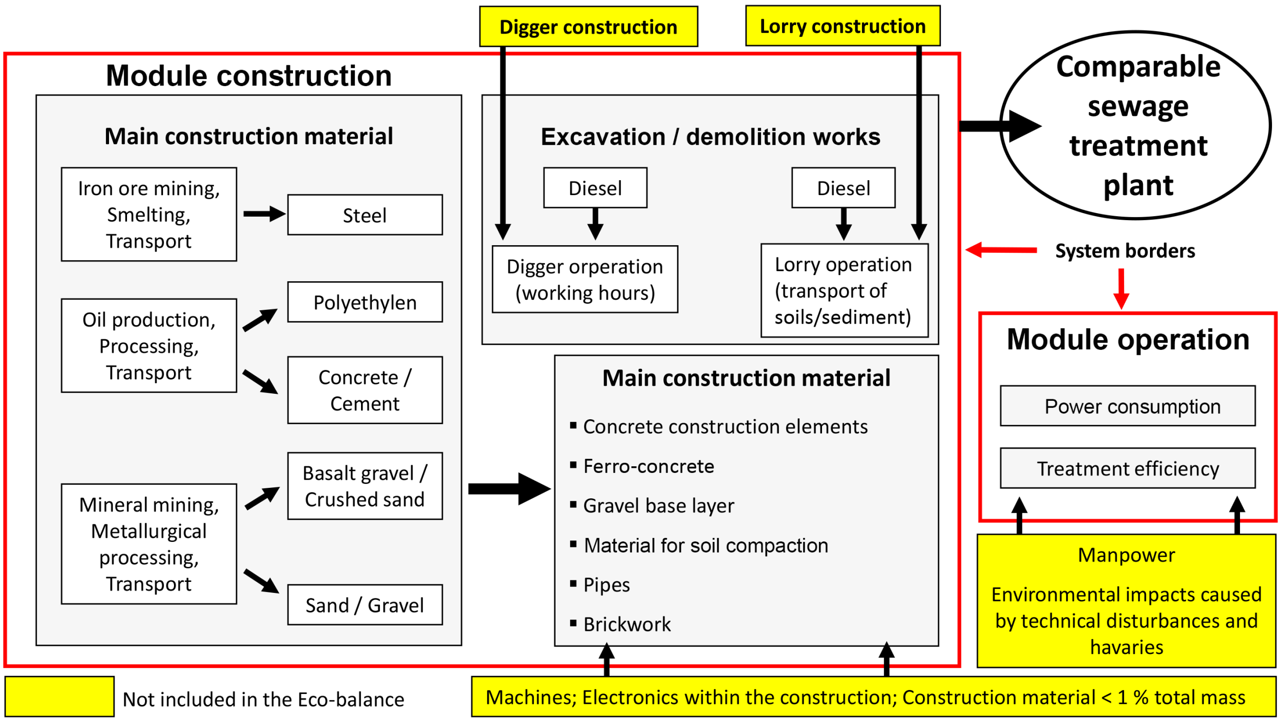

Fig. 5 Flowchart of a BIOCOS sewage treatment plant. Source: Own elaboration

Due to the very high costs for a newly constructed STP, it is not efficient to construct a new one in comparison with the continued operation of an already established pond STP. However, it is interesting to study the environmental side-effects of the old STP compared to the effects of a new one. All of the above mentioned ecological side-effects (except the direct disturbances of the aquatic ecosystem) cause a distinct additional load through the construction and operation of a new STP. The additional load caused by the construction and operation of an STP leads to an increase of the greenhouse emissions (CO_2-equivalent) by 299% (after 15 years of operation) and 184% (after 30 years of operation) in comparison to the continued operation of the old STP. The according values for the summer smog effect are an increase of 852% (after 15 years of operation) and 461% (after 30 years of operation) while the acidification (SO_2-equivalent) would be 567% (after 15 years of operation) and 318% (after 30 years of operation) higher for the new STP compared to the old one. The energy demand for the construction and operation of a new STP compared to the old one would be 212% higher after 15 years and 141% higher after 30 years (cf. *Fig. 6*). Overall, the ecological side-effects of the construction of a new STP get less severe the longer the new plant is operational, but even after 30 years of operation the new STP would still have a worse eco-balance than the continued operation of the existing STP. Among all the parameters analyzed, only the direct disturbances of the aquatic ecosystem are higher (by 18% after 30 years) in the case of the continued operation of the old STP in comparison to the construction of a new STP.

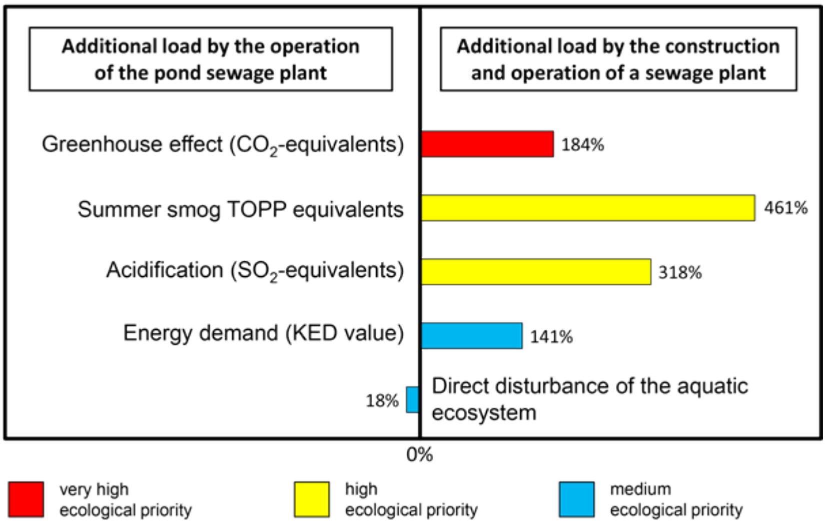

Fig. 6 *Comparison of the old and a newly constructed sewage treatment plant regarding the additional load through selected effect categories for further 30 years of operation. Source: Own elaboration, based on Klöpfer and Grahl (2009)*

4.3 Socio-economic and demographic analyses

The questionnaire revealed that 54% of the inhabitants (226 of 419) of the community Dirlammen are retired. 17% are working in the service sector, 13% in the public survey sector, 10% in the production sector, 3% in the construction sector and 3% in agriculture. This is a very common retirement and employment structure for rural areas in Germany.

30 households, equaling one third of the inhabitants, took part in the study. 93% of all interviewed individuals expressed their protest against additional costs caused by a new STP. 3% would even leave the village as they could not afford the additional financial burden, while another 4% chose to not answer this question.

In consequence of the ongoing demographic development (*WeKaDe* 2017), a considerable decrease of the population both in the community of Dirlammen and in the municipality of Lautertal is expected during the next decades. Between 2000 and 2010, the total population number decreased by 8.3% in Dirlammen and by 14.5% in Lautertal. Projecting this trend into the future, by 2030 Lautertal will have lost another 20% of its population (-500 inhabitants), while the decrease in Dirlammen will be approximately 14% (*WeKaDe* 2017). This downward trend is caused by aging and emigration. Among the emigrants, the age group of young people (<20 years old) dominates. 40% or 250 of the 450 persons in this age group will probably migrate to larger cities until 2030. The age groups 20-45 and 45-65 will also be affected by a significant reduction during that time frame. Only the age group older than 65 years will grow as a result of aging (*IKEK* 2013). Thus, based on this projection, the total population in 2050 could be as small as 296 for Dirlammen (at present: 419) and 1,343 for Lautertal (at present: 2,514). The continued depopulation of the rural communities will lead to a considerable reduction of the resultant wastewater (cf. *Hillenbrand* et al. 2010). Due to the fact that the existing sewage pipe system must be maintained regardless of the population relying on it, these costs have to be shouldered by fewer people. Thus the individual financial burden will significantly increase during the next decades – even without the construction of a new STP. This and the expected under-utilization of the existing STP (caused by the reduced amount of wastewater) render any plan for the construction of a new STP non-viable.

5. Conclusion

Based on the results mentioned above, the continued operation of the existing pond sewage plant in Dirlammen can be recommended (*Fig. 7*). Pond sewage plants can eliminate 80-90% of the BOD (Biochemical Oxygen Demand) and reduce bacteria to levels comparable to other accepted oxidation types of treatment (*Goad* 2017). Therefore, this type of treatment system meets the needs of many small and/or rural communities due to low construction costs as well minimal operation and maintenance requirements. A modern STP would improve the water quality in areas the old pond sewage plant cannot (nitrification, denitrification, and phosphorus elimination), but the eco-balance shows that this additional gain in the purification is canceled out by the ecological (and financial) impacts of the construction of such a modern STP. It seems to be more efficient to improve the purification technology of the existing pond STP, especially as the demographic development delivers a strong economic argument against such an investment. Options to improve the existing technology are for instance: retrofitting the mechanic pre-cleaning and primary treatment for the release of the (biological) tertiary treatment; reorientation of the water levels in order to prevent backwater currents; retrofitting a phosphorus precipitation step for the reduction of phosphorus concentrations and the organic load; the emplacement of additional sedentary soils for the immobilization of the biomass; the installation of a reflux system for repeated purification or the installation of impact surfaces, guidance walls and scum boards for improving the flow conditions.

Similar results were presented by *Pfeiffer* (2013) in another rural case study area. *Pfeiffer* (2013) used the same research approach and methods in another sub-catchment of the Lauter River, the Eisenbach catchment, and analyzed the Eichelhain pond STP. Independently from the Dirlammen case study, *Pfeiffer* concluded that, based on the amount of wastewater in the small community, the decreasing population number, and the financial situation of Eichelhain, the construction of a new sewage treatment plant is not advisable. This indicates that the results presented here are of general importance for many rural areas in Germany. The elaboration of a long-term affordable wastewater treatment concept is a highly relevant objective, but the results show that the future demographic development must also be taken into consideration. For choosing the right wastewater treatment for rural areas, the water quality analyses have to be complemented by an eco-balance, socio-economic and demographic analyses. Only such a comprehensive analysis and evaluation (cf. *Fig.* 7) can lead to responsible decisions about the maintenance and necessary improvements of existing sewage treatment plants, and about the potential construction of new sewage treatment plants. One important consequence of the observations and evaluations of the pipe system in Dirlammen was the definition of four damage-dependant measure categories: 1) immediate rehabilitation, 2) short-term rehabilitation, 3) medium-term rehabilitation, and 4) long-term rehabilitation. Up to

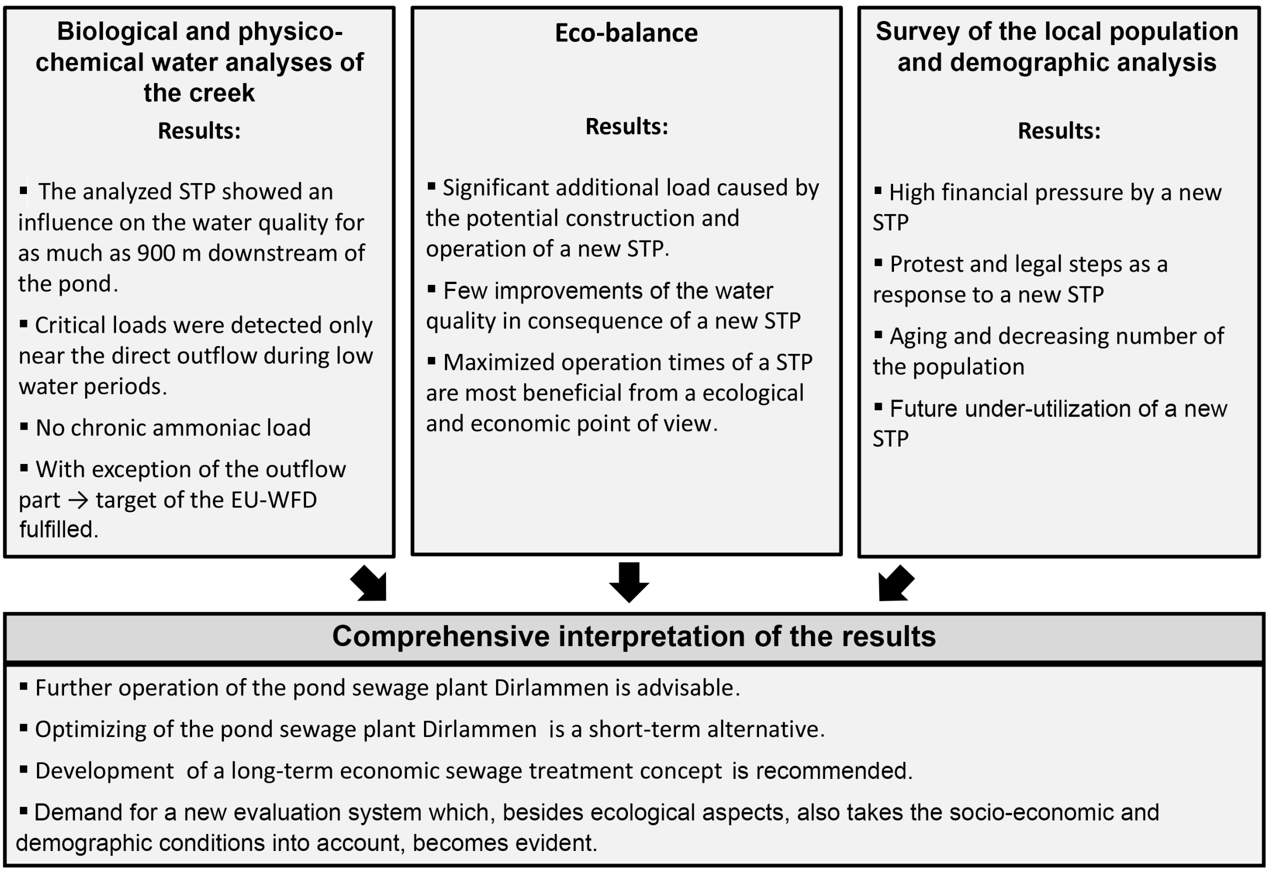

Fig. 7 Results of the trilateral analyses and comprehensive interpretation. Source: Own elaboration

now, the community has implemented the recommendation for immediate and short-term rehabilitation measures. Based on that, there is a residual demand for rehabilitation measures of about 1.1 million Euro (*Theilen* et al. 2014). A report of the Federal Institute for Research on Building, Urban Affairs and Spatial Development (*BBSR* 2017) furthermore discusses the change from a centralized to a decentralized wastewater system as one option in remote rural areas. This would result in the decommission of the existing pond system and the establishment of a number of smaller biological sewage facilities. But the same report also discusses the social and political difficulties of such a system change. Another option for the future wastewater treatment in rural areas might be the joining of wastewater pipe systems of neighboring settlements. However, it remains unclear if such measures and/or the reduced wastewater treatment demand due to the demographic change can lead to lower costs for the operation and maintenance of the technical infrastructure. Therefore, one task of the rural community administrations has to be to promote (re-)immigration of younger people into the rural communities in order to strengthen their financial base.

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