Quantification of multiple benefits and cost of stormwater management

Evaluation des coûts et bénéfices de la gestion des eaux pluviales

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RÉSUMÉ

27 techniques de gestion des eaux pluviales, actuellement en vigueur, ont été étudiées à différentes échelles : à l'échelle des immeubles (bâtiments végétalisés, utilisation d'eau de pluie), à l'échelle du quartier (infiltration, dépavage, lacs artificiels et cours d'eau, traitement décentralisé) et enfin à l'échelle du bassin versant (traitement centralisé, stockage). Pour chaque mesure, les mêmes indicateurs de performance ont été quantifiés, en se basant sur des valeurs issues de la bibliographie, des campagnes de mesures ou des résultats de simulation ; ces indicateurs concernent six avantages potentiels de la gestion des eaux de pluie (économie d'eau et énergie, amélioration de la qualité du paysage, augmentation de la biodiversité, réduction de la chaleur urbaine, amélioration de la qualité des eaux souterraines et de surface), l'utilisation indirecte des ressources (évaluation du cycle de vie) et les coûts directs. Les résultats montrent que chaque mesure a ses forces et ses faiblesses. Ainsi, pour un site donné, différentes combinaisons de techniques peuvent permettre de maximiser les avantages obtenus par la gestion des eaux pluviales. La matrice technique/avantages/coûts ainsi élaborée peut aider les décideurs à trouver les combinaisons les plus adéquates ; cette méthode est actuellement testée à Berlin en Allemagne sur une thématique d'aménagement urbaine.

ABSTRACT

A total of 27 existing measures of stormwater management were studied across scales from building level (vegetated buildings, rainwater use) to city quarter level (infiltration, de-paving, artificial lakes and streams, decentralised treatment) and catchment level (centralised treatment, storage). For each measure, the same performance indicators were quantified based on literature, monitoring and simulation results regarding six potential benefits (water/energy saving potential, improvement of landscape quality, increase in biodiversity, reduced urban heat exposure, improvement of groundwater and surface water bodies), indirect resource use (life cycle assessment) and direct cost. Results show that each measure has its strengths and weaknesses. Thus, it is expected that different combinations of measures will lead to increased benefits for different locations/settings. The developed measure-benefit/cost-matrix may support the finding of such improved combinations and is currently tested in a research project regarding its potential for problem-oriented urban planning in Berlin, Germany.

KEYWORDS

Stormwater management across scales, quantification of effects, integrated urban planning

1 INTRODUCTION

Stormwater can be managed by various existing measures at different spatial levels of a city:

- at the building level: e.g., vegetated buildings or rain water use
- at the city quarter level: e.g., de-paving of impervious areas, artificial lakes and streams, infiltration, decentralized treatment
- at the catchment area level in combined and separate sewer systems: e.g., storage activation or end-of-pipe treatment

Stormwater management that leads to evaporation, infiltration, retention or treatment of stormwater can. bring a number benefits to cities: (i) savings at building level (e.g., cooling systems) (ii) improved urban landscape quality, (iii) reduced urban heat exposure, (iv) increased urban biodiversity, (v) improved groundwater quantity and quality and (vi) reduction in negative impacts on receiving surface water bodies. Finally measures lead to (vii) use of resources and (viii) cost.

Typically, only single benefits are aimed at when stormwater measures are implemented, while the above range of potential benefits on a city level is not taken into account. One reason is a lack in a quantitative description of benefits and cost for most of these measures.

2 APPROACH

To fill this gap we evaluated the effects (i) to (viii) for a number of existing stormwater measures under the following principles:

- Quantification: all effects are evaluated quantitatively
- Comparability: each effect is evaluated with the same set of performance indicators for all the measures
- Across scales: measures include all scales from building level to the catchment area

Involved experts on stormwater management contributed the list of 27 considered measures in the seven categories: vegetated buildings, stormwater use, infiltration, de-paving, artificial lakes and streams, treatment and storage.

Each effect was evaluated by a specialist in their field. In a first step, possible goals of stomwater management were assessed and translated into a set of suitable performance indicators (Matzinger et al. 2014). In a second step, performance indicators were quantified based on literature, monitoring and simulation results, with a focus on Berlin. Within this quantification step, chosen performance indicators were also adapted to available data or changed methodologies.

Finally, for planning purposes, we attempted to simplify the collected information into a “traffic light system” for each effect: red: small benefit/high cost, yellow: moderate benefit/cost, green: high benefit/low cost. However, effects are kept separately and no overall cost-benefit is calculated. The reasoning behind this is the basic assumption that all the measures have strengths and are suitable for specific settings (that is why they are implemented); the perfect measure does not exist.

3 RESULTS AND DISCUSSION

Figure 1 shows the results for one exemplary indicator (reduction in total suspended solids) regarding the benefits for receiving rivers and lakes (surface water). The plot shows a wide range in the indicator value across measures, but also within measures. Nevertheless, it is possible to distinguish the measures in terms of their performance. In this case the categorisation was done by dividing the range between 0 and the maximum median of all measures by three; the three resulting thirds were then assigned with a red (< 300 kg ha^{-1} yr^{-1}), yellow (300-600 kg ha^{-1} yr^{-1}) and green (> 600 kg ha^{-1} yr^{-1}) signal.

Figure 1 is a representative example for the evaluation. However, depending on the effect and the system of evaluation more (e.g., for biodiversity) or less (e.g., for groundwater or urban climate) data points were available. Regarding the categorization, boundaries were chosen differently in some effects, taking into account some existing effect-specific assessment approaches.

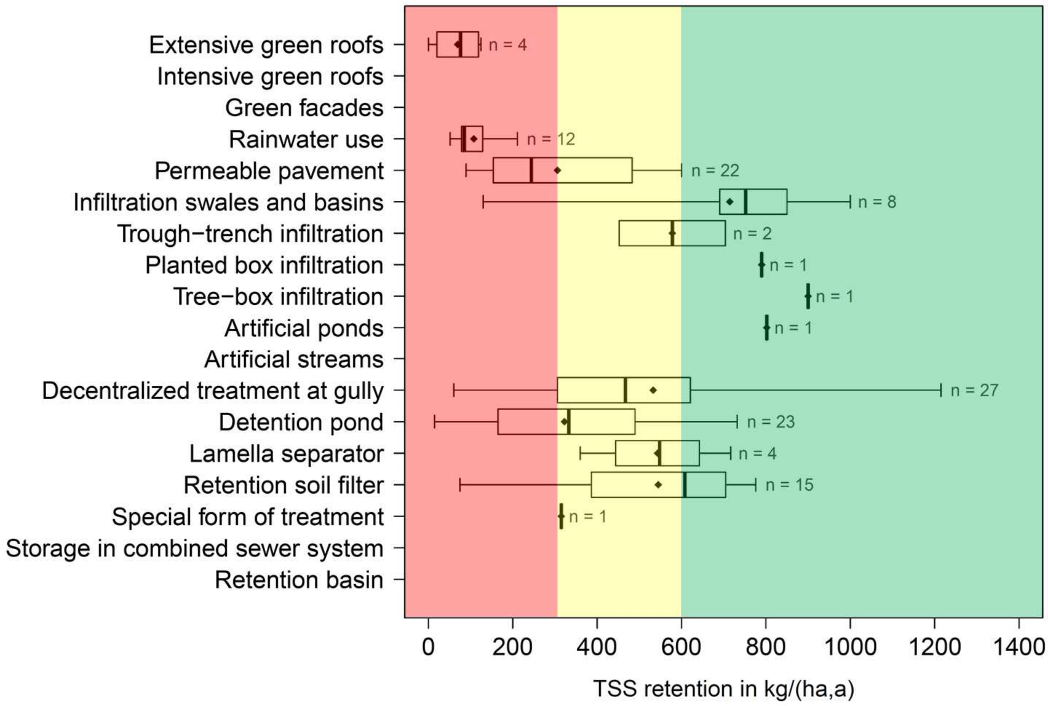

Figure 1: Quantification of the indicator “Reduction in loading of total suspended solids”. Values are based on literature and own measurements. For some measures no information was available, other single measures were combined, since effect is the same for TSS retention. Colours indicate categorisation of measures (see text).

Table 1 shows an overview of all the evaluated performance indicators for each of the eight effects, as well as measure categories (or single measures) that reached a green evaluation in the categorization. The results are still preliminary and will be extended further with new monitoring results and additional data.

At a first glance, we find that each measure category reaches top performance for some effects, but none reaches top level for all effects. This verifies our basic assumption that all measures are effective. For instance (i) runoff peaks from one-year storm events can be highly reduced by vegetated roofs, infiltration systems and retention soil filters (> 67 %), whereas (ii) urban heat exposure is greatly improved by artificial lakes and infiltration systems that are combined with trees (> 70 h yr^{-1} reduced times of strong heat stress), (iii) area-specific cost are lowest for measures at catchment scale and simple decentral measures, such as simple swales or extensive green roofs and (iv) maximal energy saving from cooling in buildings is only reached by adiabatic cooling with moderate effect (yellow) for green facades.

4 OUTLOOK & CONCLUSIONS

- For the first time (to our knowledge) a consequent *quantification* of benefits and cost of measures of stormwater management was attempted.
- Despite large ranges in values, quantitative performance indicators can help to choose the right measures or, at least, prevent choosing wrong *measures for a specific goal*. The performance indicators highlight additional benefits of decentralized measures on city scale, which are typically not considered.
- First results indicate that measures on very different scales can reach similar benefits. Thus, it is also likely that a combination of measures across scales can *improve the overall benefit at city-level*.
- The *suitability for actual planning* of stormwater management on the scale of city quarters is currently *tested in Berlin* (Nickel et al. submitted).

Table 1: Quantitative performance indicators and suitable stormwater measures per effect (preliminary results)

Effect	Performance indicators [unit]	Measures with high performance	
		Threshold [1]	Measure categories [2]
	Benefits		
Building level	Water saving potential [% of service water]	> 67 %	B, E
	Energy saving potential [% of energy for cooling]	> 67 %	B (adiabatic cooling)
	Reduced stormwater fee [%] [3]	> 67 %	D, E
Landscape quality	Complexity [scale of 1 to 5]	< 1.7	none [4]
	Coherence [scale of 1 to 5]	< 1.7	
	Readability [scale of 1 to 5]	< 1.7	
	Involution [scale of 1 to 5]	< 1.7	
Urban climate	Reduction in number of nights > 20 °C [days yr^{-1}]	> 1	E
	Reduction in number of heat days > 30 °C [days yr^{-1}]	> 1	E, D (tree-box-filter)
	Reduction of strong heat stress (UTCI) [hours yr^{-1}]	> 24	A, D, E
Biodiver-sity	floristic α-diversity [# of species]	> 12	A, D
	faunistic α-diversity [# of species]	> 25	A, D, E
	floristic β-diversity [# of species]	> 2	A, D, E
	faunistic β-diversity [# of species]	> 2	E
	red list plant species [# of species]	> 0.5	A
	red list animal species [# of species]	> 0.1	E
	novel urban ecosystem plant species [# of species]	> 8	A, D
	habitat diversity [# of habitats]	> 2	A, E
	distance to next green area [m]	< 20	D, E
	mobility (barriers) [scale of 0 to 6]	> 1.5	A, D, E
Ground-water	Change in contribution of groundwater recharge to water balance [%]	<> 0 [5]	C, D
	Zinc infiltration [% of inflow concentration]	< 100	all
	Chloride infiltration [% of inflow concentration]	< 100	A, B, E, F, G
	Sulphate infiltration [% of inflow concentration]	< 100	A, B, E, F, G
Surface water	Annual runoff reduction [%]	> 67	B, D, E
	Reduction of one-year peak runoff rate [%]	> 67	A, D, E, F (retention soil filter), G
	Reduction in Phosphorus loading [kg ha^{-1} yr^{-1}]	> 2.7	D, E, F
	Reduction in total suspended solids [kg ha^{-1} yr^{-1}]	> 600	D, E, F
	Cost (direct and indirect)		
Direct costs	Investment cost [€ m^{-2} connected impervious area]	< 25	A (extensive green roof), D, F, G
Resource use	Global warming potential [kg CO_2-eq m^{-2} connected impervious area]	< 1000	A, B, D, F, G

1 measures that perform better than this threshold are assigned a green signal (high performance)
2 Measure categories: A - vegetated buildings, B - rain water use, C - de-paving, D - infiltration, E - artificial lakes and streams, F - treatment, G - storage in the sewer system; if only one measure within one category reaches high performance, measure is indicated in parentheses
3 Berlin-specific
4 all measures that include green or water elements were assessed as “yellow” (moderate benefit, score between 1.7 and 3.3), given the variation in personal preference of people regarding landscape
5 depending on local settings an increase or decrease in groundwater recharge may be aimed at

ACKNOWLEDGEMENT

The presented results were established within the project KURAS, mainly funded by the German Ministry of Education and Research (BMBF) in the framework of the FONA (Research for Sustainable Development) initiative. The projects are co-financed by contributions of the participating SMEs and large-scale enterprises. KWB received co-financing from Veolia Water and Berliner Wasserbetriebe.

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