Assessment of structural stormwater measures in Tehran through indicators of sustainable development

Indicateurs de mesure d'une gestion durable des eaux pluviales à Téhéran, Iran

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RÉSUMÉ

Cet article propose des mesures structurelles de gestion des eaux pluviales pour en prévenir les effets négatifs tels que ceux connus par Téhéran du fait de son expansion difficile. Ces mesures doivent intégrer le concept de développement durable dans la gestion des eaux pluviales. L'étude s'est centrée sur 4 mesures structurelles et durables adaptées au 22ème district de Téhéran. Elles comportent : un bassin de rétention étendu, une tranchée d'infiltration, un système de filtration sur sable et une chaussée perméable. De façon à évaluer leur apport dans le cadre de la gestion durable des eaux de pluie à Téhéran, un ensemble d'indicateurs a été développé. Le déversoir d'orage, qui fait partie des mesures classiques, est également inclus dans l'évaluation. Les indicateurs de mesures sont répartis en indicateurs économiques, environnementaux et sociaux, et sont donc représentatifs d'une gestion durable des eaux de pluie. Un score final permet d'évaluer individuellement chaque mesure et sa contribution spécifique – en comparaison des autres mesures – à la gestion durable des eaux pluviales. Cette évaluation a révélé que les grands bassins de rétention et les chaussées perméables sont les méthodes s'inscrivant le mieux dans cette gestion durable. Une combinaison des deux méthodes est donc proposée afin de faire face aux problèmes provoqués par les eaux pluviales à Téhéran dans un cadre durable.

ABSTRACT

The paper suggests structural stormwater measures that should prevent negative impacts of stormwater evolved from Tehran´s drastic expansion. These measures should incorporate the concept of sustainable development in stormwater management. The study selects four structural sustainable stormwater measures appropriate for the 22nd district of Tehran. These are: extended detention basin, infiltration trench, sand filter and pervious pavement. In order to assess their contribution to sustainable development in stormwater management in Tehran one indicator set is developed and the storm sewer, as conventional measures, is also included in the assessment. The indicators that should describe the measures individually are split into economic, environmental and social ones and thus represent the concept of sustainable development in stormwater management. By applying the scoring method final scores of the measures are gained. The final scores state to which extent each measure – relative to the other selected measures – incorporates the concept of sustainable development in stormwater management. This assessment reveals that extended detention basins and pervious pavement are incorporating the most and therefore a combination of both measures is proposed to tackle the problems due to stormwater in Tehran in a sustainable way.

KEYWORDS

Indicators, Stormwater Management, Structural Measures, Sustainable Development, Tehran;

1 INTRODUCTION

Over two hundred years as the capital of Iran, Tehran has developed from a 7.5 square kilometer city with 15.000 inhabitants into a tightly packed city with 8 million people sprawling over 868 square kilometers. Actually it was from the 1960ies on that Tehran experienced a drastic increase in population numbers. The White Revolution[1] aftermath and the Iran-Iraq war are reasons behind this migration to Iranian cities. Hence Tehran established itself as a gigantic Iranian metropolis within the last two decades. Tehran´s population explosion and urban expansion raised various problems, also in respect to stormwater infrastructure systems. Actually the stormwater system did not keep pace with the speed of the urbanization and therefore stormwater is negatively affecting the urban life and environment in Tehran today. Inconveniences within the drainage system in Tehran, such as bad river quality and floodings, are some examples. Evidently, there is a lack of effective stormwater management throughout the city.

Generally speaking the expansion of urban areas leads to the change from natural landforms and vegetative covers to unnatural and impervious areas. Regarding stormwater this has two major effects: effect on stormwater quantity as well as on stormwater quality. With the urbanization the sealed surfaces (streets, roofs, ect.) expand. At the same time the stormwater runoff volume is altered because stormwater cannot infiltrate into the ground any more. Although Tehran has a semi-arid climate and an annual precipitation of 218 mm the existing drainage facilities face constrictions and lack of freeboard today. This is primarily because there were not designed for such altered stormwater runoff. Therefore Tehran is struggling with minor floods that occur mostly in the southern and central regions where flows are biggest (Gibb A. & Partners, 1975) (Mühr, 2007).

Apart from increasing stormwater runoff quantities the rise of population numbers, urban expansion and incline of impervious areas also affect the stormwater runoff quality in negative terms. Pollutants from non point sources (e.g.: debris, litter) are accumulating on impervious areas, collected by stormwater runoff and discharged into receiving waters. Therefore the concentration and types of pollutants in stormwater runoff are increased, leading to contamination of receiving waters. In the case of Tehran the actual situation of the quality of receiving waters does not look very pleasant. Especially the central and southern streams and rivers show low water quality. However, this is not only due non point source pollution but also due to point source pollution. Pollution loads of point sources often contain very harmful substances and therefore water quality of Tehran´s streams and rivers turns to be a hygienic issue for the city, especially in the case of flood events (Municipality of Tehran, 2009).

Another negative effect of the urbanization in Tehran is the fact that the impervious areas prevent stormwater from infiltrating into the ground. Tehran´s water supply system relies mainly on groundwater. So the lack of recharge and the increase in water demand lead to a decline of the groundwater table. Considering all these problems regarding stormwater an adoption of Tehran´s stormwater infrastructure to current conditions deems necessary (Jahani & Reyhani, 2006).

This paper is conducted in cooperation with a new stormwater management master plan for Tehran that is currently being updated by the Municipality of Tehran. The paper should suggest effective stormwater measures that involve the concept of sustainable development and decrease negative stormwater impacts. Thus the 22nd district of Tehran is chosen as case study area which is located in the north-west of Tehran. The 22nd district, known as Khargoosh darreh, forms a semi-urban area where development is under way. It features high degree in future development, currently very low population density and respectively, free areas of space available. This means that stormwater measures could be easily integrated in the establishment and construction of the urban surroundings.

For the size of the paper the study only deals with structural stormwater measures. However, structural and nonstructural measures are both part of successful stormwater management. The concept of sustainable development is very site specific and therefore the selected measures should be assessed for their actual contribution to sustainable development in Tehran´s stormwater management through appropriate indicators. For relative reference one conventional measure, a storm sewer, is included in the assessment which should reveal the differences of conventional and sustainable structural stormwater measures in terms of sustainable development. The final result forms a ranking of the selected measures by their contribution to sustainable development of stormwater management.

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[1] White Revolution was a program of reforms impeded by Shah Mohammad Reza Pahlavi from 1962, primarily to abolish the feudal system (Encyclopaedia Britannica, 2009).

Summing up the key target of this paper is the selection of sustainable structural stormwater measures for the 22nd district of Tehran and the assessment of their contribution to sustainable development in stormwater management through appropriate indicators in the 22nd district of Tehran for the future.

2 METHODS

2.1 Sustainable development within stormwater management

The Brundtland Report and the Agenda 21 (Rio declaration) have set the focus on the long term sustainability of our environment. In order to ensure human wellbeing over time sustainable development must require the protection of environmental, social and economic development (UN, 2002). As a result there was a change in the approach of stormwater management. Instead of conveying it further downstream stormwater is seen as a positive resource for the urban environment today. The new integrated approach is called sustainable stormwater management and has been introduced as modern practice for drainage of urban areas. Overall stormwater management involves different practices and strategies undertaken to regulate runoff under various conditions (Urban Water Resources Council of the American Society of Civil Engineers & the Water Environment Federation, 1992). The basis for the current trend in stormwater management forms the entanglement of quantity and quality of runoff and amenity value of surface waters; whereas quantity was the only characteristic feature of the traditional urban storm drainage which is illustrated in Figure 1 (Pöyry & Mahab Ghodds, 2009).

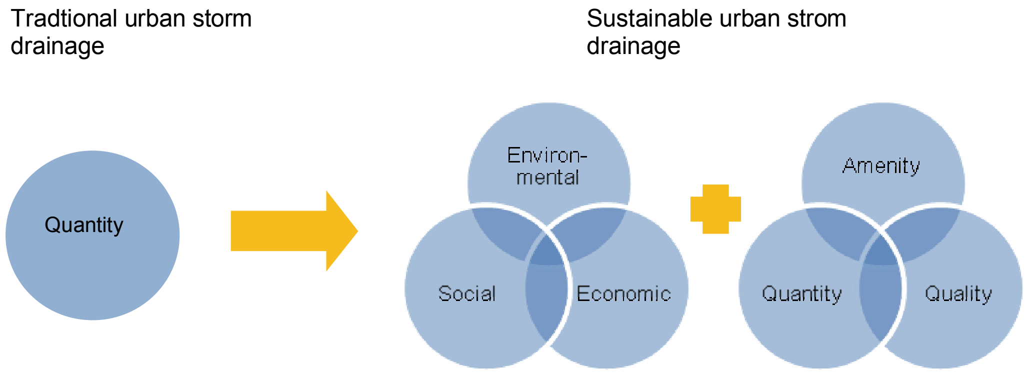

Figure 1: Towards a more sustainable urban storm drainage (Stahre, 2004)

Shaver et al. (2007) assign the focus of amenity, quantity and quality to the sustainable urban drainage systems (SUDS) that is one out of several terminologies for sustainable stormwater management worldwide. The synonym for SUDS in Europe could be low impact development (LID) for the USA: a very similar system that takes into account stormwater management as stormwater control throughout the landscape. Significantly for modern development of stormwater management are best management practices (BMPs) which promote long term success of sustainable systems. BMPs comprehend various technologies that are applied in any of the accounted approaches worldwide (Department of the Environment and Heritage, 2002) (Peluso & Marshall, 2002).

Generally speaking sustainable stormwater management is also defined as a water sensitive approach for the stormwater dimension. In this context SUDS, LID and BMPs are the most systems referred to. Basically all approaches have the similar background in achieving sustainable stormwater management (Patawalonga Catchment Water Management Board et al., 2002). Hence all systems aim towards minimizing the hydrological impacts of urban development on receiving waters and surrounding environment, and especially towards the reduction of pollution deriving from non point sources (Shaver et al., 2007).

2.2 Structural sustainable stormwater measures

Sustainable stormwater management encompasses practices and measures that are all very similar regardless the type of approach. There is one differentiation which is between structural and non structural measures. In general structural and non structural measures are known, whereas structural measures involve any physical construction or engineering technique and non structural are those measures that focus on policies, laws, public awareness and education (Prevention Web, 2009). Examples for structural measures are stormwater constructed wetlands and stormwater retention ponds whereas public education and awareness campaigns are categorized as non structural practices.

Considering the focus of this study, structural measures, there are a set of strategies worldwide. Among all, the report of Daywater (Middlesex University, 2003) provides the most comprehensive information because the report itself is supported by a literature review on the selected topic. Additional Information upon measures is gained from the following stormwater management manuals and reports: Missa et al. (2005), AMEC Earth and Environmental Center et al. (2001), Center for Watershed Protection (2002), Melbourne Water (2005), Auckland Regional Council (2003). An overview over structural sustainable stormwater measures is given in Table 1.

Practise group	Detailed description	Practise examples
Storages	Permanent pools (or shallow marsh areas or extended detention storage) that treat water	Detention basin Retention pond Constructed wetland
Infiltration	Capture (and temporal storage) of water before infiltration into soil	Infiltration basin Infiltration trench Soakaways Sand filter
Biofiltration	Capture (and temporal storage) of water before passing it through a vegetation filter	Swales Filter strip Filter drain
Pervious surfaces	Hard surfaces that can infiltrate rainwater through	Porous pavements Porous asphalt
Evaporation	Capture rainwater before evapotranspiration through plants	Green roofs
Harvesting and re-use	Temporal storage of water by technical means	Rainwater tanks (Rainwater harvesting) Cisterns and rain barrels
Pollutant traps	Traps for interception of coarse particulate matter and trash and debris by various means	Gross pollutant traps
Combined systems	Combination of two or more of measures	Raingarden

Table 1: Overview of most common structural practices for sustainable stormwater management (Center for Watershed Protection, 2002) (Middlesex University, 2003)

(Auckland Regional Council, 2003)

3 RESULTS

3.1 Selection of structural sustainable stormwater measures

The first result of the paper comprises structural sustainable stormwater measures that would fit best the site conditions of the 22nd district of Tehran. Therefore the measures must fulfill certain criteria. They must

- be feasible for semi-arid climate and high permeability of soil,
- have good performance regarding water quality and water quantity,
- provide groundwater recharge.

Taking into consideration these criteria the following measures are suggested for the 22nd district of Tehran:

- Detention basin
- Infiltration trench

- Sand filter
- Pervious pavement

All four measures are adaptable to semi-arid climates and provide stormwater quality as well as stormwater quantity enhancement. Infiltration trench and pervious pavement are measures whose design focuses on groundwater recharge. Detention basin and sand filter are not designed primarily for groundwater recharge, but soil infiltration is possible through careful design. In the case of detention basins the design as extended detention basin is recommended in order to increase stormwater detention time, hence improve the quality of the outflow.

Having found feasible measures for the 22nd district, the next step includes the design and calculation of each single chosen measure in order to get an idea of their characteristics. The Daywater report (Missa et al, 2005), the Georgia Stormwater Management Manual (AMEC Earth and Environmental et al., 2001) and the report of New Zealand Guidelines (Auckland Regional Council, 2003) provide the necessary information. In this case study all measures are dimensioned for a design storm with 5 years and for a suitable size recommended by the manuals.

At this point it is worthwhile to mention that the focus is on drainage areas such as roads and parking spaces. Roofs were not taken into account because rooftop infiltration is mandatory in the 22nd district of Tehran.

In order to be able to compare conventional and sustainable stormwater measures for their contribution to sustainable development the storm sewer as conventional measure is included in the calculation and assessment as relative [Table 2].

Measure	**Catchment area [ha]**	**Size of measure [m³]/ depth [m]**	**Treatment volume [m³]**	**Construction cost [€]**
Extended detention basin	4,5	450/ 2.1	727	36 353
Infiltration trench	1	200/ 1.6	150*	35 836
Sand filter	1	65/ 1.8	162	42 951
Pervious Pavement	0,5	1250/ 0.08	48*	18 576
Storm sewer	4,5	1800 m Length/ Ø 350 mm	97	433 800

Table 2: Examples for design of selected structural stormwater measures and storm sewer

*In the calculation by Missa et al. (2005) the impermeability index is not taken into consideration and therefore the total runoff excluding impermeability index figures the input for the calculation of the treatment volume

3.2 Appropriate indicators

One of the outputs of the UN conference in Rio de Janeiro in 1992 was the call for the development of sustainability indicators which assess interactions between environmental, economic and social development. By setting indicators the contribution to sustainable development can be estimated. Indicators are, together with criteria, tools to make a final decision on the objectives.

Within the context of sustainable stormwater management Revitt et al. (2003) have developed the most detailed criteria and indicator set which provides the basis for the ongoing study.

Instead of the nomenclature of Revitt et al. (2003) the nomenclature of ISO 24511 (ISO, 2006) is used for the indicator set. To the authors the ISO nomenclature seems more general and the more recent study. Therefore the nomenclature for the indicator set in this study comprises criteria, indicators and values including their unit. For the study the indicator set of Revitt et al. (2003) has been adopted to the given conditions and requirements. Hence the criteria are grouped in social, environmental and economic criteria and state the most important characteristics for sustainable stormwater measures in the 22nd district of Tehran.

Revitt et al. (2003) present a whole range of potential indicators but only some are substantial for this study case because they should fulfill the following principles:

- Easy to understand
- About something that can be measured and is believed important
- Communicative
- Relevant for political decision-making and control
- Quantifiable

- Feasible
- General and simple

According to these principles a set of 17 indicators, divided into economic, environmental and social dimension is developed based on the work of Revitt et al. (2003). On purpose the indicator set comprises 7 social, 6 economic and only 4 environmental indicators, that most suite the site conditions. The indicators describe the criteria, which define the objectives of sustainable stormwater management and thus the relevant measures. Indicators are measurable parameters. Hence values are assigned to indicators. In this case study the values for the single structural measures are taken from profound studies on structural stormwater measures (c.f. list of references). Wherever the values cannot be directly indentified through ordinal numbers, subindicators are chosen to describe them further [Table 3].

Moreover weights are displayed in the table below. The weights are necessary for the assessment and final ranking and should identify the preferences of the decision maker. By applying the scoring method a decision should be revealed. In this case study the weights are assigned by the leading consultant of the stormwater management master plan for Tehran, as representative for the decision maker. In total the weights give 100.

Economic Criteria	**Indicator**	**Unit (value range)**	**Weight**
System reliability	- Probability of system failure	- % probability (0-50%)	- 5/100
System flexibility, adaptability and potential for reuse	- Ease of retrofitting *Subindicators:* Ease of modification Potential for recycling major system components Use for another function than stormwater management	- Number of yes (0-3x yes)	- 2/100
System robustness	- System Robustness (if O&M missing) *Subindicators:* If no maintenance If no maintenance and additional litter input If no maintenance and dry periods (arid climate)	- Number of yes (0-3x yes)	- 8/100
Operation and maintenance requirements	- Frequency for operation and maintenance	- Frequency/ year (0- 12/ year)	- 6/100
Life cycle costs	- Capital costs - Operational costs	- €/ ha drainage area (11 109 – 96400 €/ ha) - €/ ha drainage area* year (160 – 4500 €/ha)	- 8/100 - 7/100
Environmental criteria	**Indicator**	**Unit (value range)**	**Weight**
Water volume impact	- Groundwater recharge - Flooding attenuation in receiving Waters	- % of attenuated stormwater (0-100%) - % of storage volume/ treatment volume (0-100%)	- 10/100 - 5/100
Water quality impact	- Quality of water outflow	- Average % removal rate (0-65%)	- 1/100
Habitat and ecological diversity	- Number of key species Introduced in receiving waters	- 0,1….n (0-3)	- 3/100
Social criteria	**Indicator**	**Unit (value range)**	**Weight**
Social inclusion and multifunctional use	- Level of amenity provision *Subindicators:* Landscape enhancement/ structure Recreation Sports Part of urban design	- Number of amenities (0-3)	- 6/100
Educational aspects	- Use as demonstration site *Subindicators:* For schools For universities For public	- Number of yes (0-3x yes)	- 4/100
Stakeholder Acceptability	- Acceptance of onsite treatment *Subindicators:*	- Number of yes (1-4x yes)	- 6/100

	Public Ministry of energy (water) Operator (municipality) Ministry of Tehran (urban planning) - In-basin quality condition Subindicators: Trophic state Smell Stagnant water/ mosquitos	- Number of yes (0-3x yes)	- 8/100
Resource use	- Material use for construction - Energy use for construction - Land take	- Total quantity for design/ catchment area*year - Energy units for design/ catchment area*year - % of impervious catchment area	- 3/100 - 3/100 - 6/100

Table 3: New criteria and indicator set including units and weights for the assessment

3.3 Assessment of contribution to sustainable development

Setting the weights is the first step of scoring. The next step involves the transformation of the values into scores, 1-5-10 respectively, and 0 if it totally fails a certain threshold (e.g. completely no amenity). Here the grade of the performance regarding the principles of sustainable stormwater management of the values is assessed. In other words it is stated if the measure is performing well or bad in a certain indicator. After multiplication of scores times weights the products for each sphere of sustainable development are summed up. Ideally each pillar should be maximized and all three pillars should be in balance. In the assessment of this study it can be seen that the extended detention basin is achieving the highest and at the same time most equal sum of scores for each pillar relative to the other selected measures and with regard on the local situation [Figure 2].

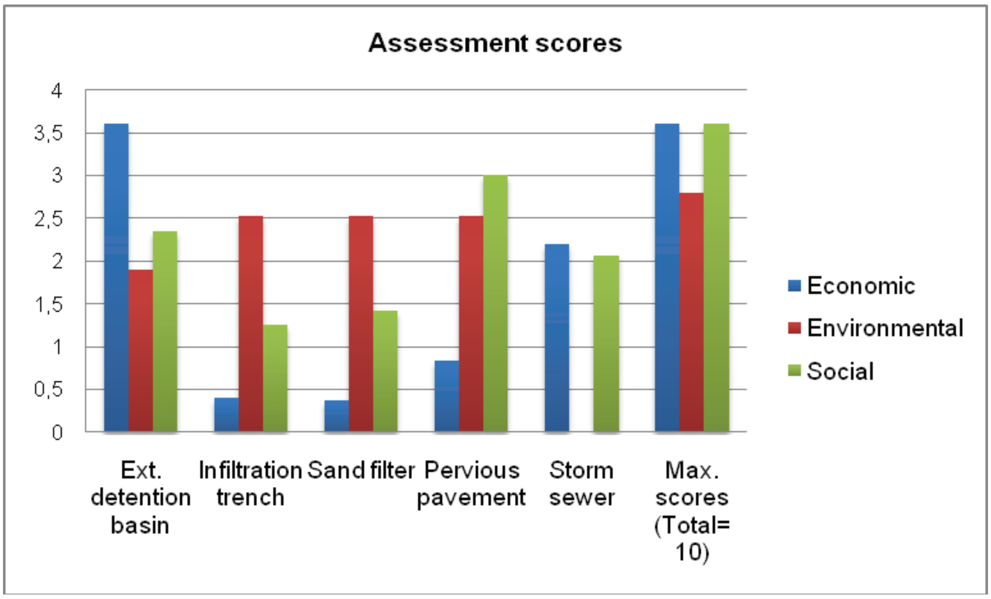

Figure 2: Assessment scores

4 CONCLUSIONS

Looking at the scores and values of the indicators of all measures, it is very clear that the extended detention basin is achieving good results in the assessment because it accounts most often the highest scores. The extended detention basin is a simple measure with low construction and operation costs for big drainage areas. Analysing the second best measure it can be seen, that pervious pavement is assigned a good average score for all indicators. Pervious pavement is a measure with a high amenity value, low land use and a high acceptability because it can be integrated very well in the urban area. The other two structural measures have similar scores for each pillar. This is because both measures are measures with high operational costs and their ease of retrofitting is low.

Apart from the sustainable structural measures it is notable that the conventional measure is not far off the others in terms of the economic and social part but totally fails in terms of the environmental part. This is because the conventional system has major advantages concerning frequency of operation and maintenance, operation costs, land use, in basin quality condition and total acceptance, but features no definite environmental benefit.

Considering the size of the different structural measures the measure for the largest designed catchment areas has achieved the highest scores. However, for measures that treat runoff from large catchment areas also the supply systems has to be taken into account. Thereafter costs and maintenance of proper sewer system for stormwater supply must be regarded. This shifts the economic score of extended detention basin closer to the economic score of pervious pavement of the assessment, but does not change the final ranking. On the other hand pervious pavements are structural measures with the smallest catchment size. Small drainage areas do not require a proper sewer system. Instead, pervious pavement measures are fed by superficial drains which have negligible costs compared to sewer system costs. It can be concluded that the layout of the structural measure as decentralized or centralized measure effects the final score remarkably.

By applying the scoring method the process is changed from a rather objective to a subjective decision maker process. The decision maker assigns different factors of importance to all indicators. This is done regardless the dimension of sustainable development. At this point it must be noted that the costs have been assigned with a weight of only 15%.

Concerning validity it can be said, that the selected measures are approved measures in semi arid/ arid climates in the U.S [c.f. (Scholes, Revitt, & Ellis, 2003)] and the indicators are based on approved literature. Nevertheless sufficient literature studies and results concerning this topic in the Far East have not been published yet. Tehran´s background is different to the westernized ideas and indicators given in the literature. Therefore it deems necessary to implement this proposal and prove its validity for Tehran as an example for the Far East. At the same time non-structural measure must be taken into account in order to perfect the results. Apart from this a sensitivity analysis of the indicators could probably be efficient to figure the robustness of the assessment.

However, at first it would be very beneficial for this study to receive concrete information about the local situation and the opinion of the decision maker and all stakeholders. Detailed data could render more precisely the indicators, the values and weights, thus the final scores.

In regard to the general analysis and assessment of this study it can be concluded that two measures could perform well within sustainable stormwater management in the 22nd district of Tehran. The paper comprises a theoretical study which means that all data is obtained and estimated in form of other case studies, but not from the selected site directly. This means that the next and future step should include the application of the output of this study. Finally it can be said that indicator sets prove to be useful tools for decision makers and display all necessary information in a very comprehensive way. Thus the scoring method is an easy way to structure and analyze the decision problem.

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