NUTRIENT MANAGEMENT AND INSTITUTIONAL COOPERATION AS CONDITIONS FOR ENVIRONMENTALLY SAFE WASTEWATER IRRIGATION: THE CASE OF HANOI, VIETNAM

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Abstract

Hanoi is rapidly growing in population and in economic activities. Increasing volumes of domestic and industrial wastewater flows are discharged mostly untreated into the drainage system. At downstream level, these polluted, nutrient rich waters are used for irrigation. Nutrient concentrations in the polluted waters are high enough to at least partly fulfill crop nutrient requirements. Yet, as farmers also apply organic and mineral fertilizers total application of nutrients is excessive. This makes irrigated agriculture a source of pollution where it has the potential of being a step in environmental treatment of wastewater.

Field research was done in Đong Du village in the peri-urban district Gia Lam in order to define the conditions for a sustainable and environmentally safe wastewater irrigation system. The main cash crop in this area is spiny coriander, *Eryngium Foetidum (L.).* The communal irrigation system takes water from Cau Bay River, which receives domestic and industrial wastewater effluents. For the main crops nutrient savings and/or additional nutrient requirements were calculated by a Microsoft Excel based model. Outcomes were compared with the actual nutrient application by farmers. This showed that, on average, farmers oversupply nutrients. The large range in nutrient application levels between farmers makes clear that farmers have low insight in nutrient management.

Rather than water quality, the main problems farmers themselves perceive are related to water quantity, caused by poor irrigation system design and lack of maintenance. To improve the situation, the physical infrastructures as well as the management systems related to wastewater and irrigation need to be developed in a combined effort. It should result in peri-urban irrigated agriculture being an integral part of Hanoi's urban water management system. With the use of chain theories it is shown that vertical integration of urban agriculture is needed. A co-evolutionary institutional and technological approach for developing environmentally safe peri-urban agriculture is proposed that deals with both altering physical flows as well as its supportive urban water management system.

Introduction

Hanoi is the capital and second largest city of Vietnam. It is located in the fertile Red River delta. In the twentieth century Hanoi developed quickly to a population of over three million at present. According to the lowest growth scenarios for 2024 of the General Statistical Office, Vietnam will have a population of 96 million people, of which 32% will live in urban areas. An important driving force

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behind the urbanization of especially Hanoi and Ho Chi Minh City is the reengagement to the world economy in the late 1980's. This reform, locally referred to as *doi moi,* reduced the role of the state and opened the Vietnamese economy up to foreign capital (Van den Berg *et al.*, 2003).

Hanoi municipality consists of seven urban city districts and five peri-urban districts. The peri-urban districts form about 91% of the municipal area. Hanoi's population had an annual growth rate of 3.1% in the period 1990-1999. The largest part of this growth comes from migrants, temporary and permanent, registered and not registered (Van den Berg *et al.*, 2003). This urban population growth and the rapid economic growth are important factors for the changes that have taken place in (peri-)urban irrigated agriculture in Hanoi and the pollution of its environment. Agriculture plays an important role in Hanoi as it provides 60-80% of the perishable vegetable products for the local market (Van den Berg *et al.*, 2003). A large part of the population is at least partly dependent on agricultural incomes.

Urban domestic and industrial wastewater flows in Hanoi are mostly discharged untreated in Hanoi's surface water bodies. One could state that rivers flowing through the boundaries of Hanoi are a part of the sanitation and drainage system of Hanoi municipality. These rivers are used downstream as source for irrigation water in open space peri-urban agriculture. With the increase of urban water demand, fresh water resources will be a scarcer commodity in many areas around the world (Raschid-Sally *et al.*, 2005), while wastewater flows increase. Hanoi will not be the exception. Moreover, the wastewater flows may result in severe deterioration of the fresh water resources if governments are not able to install proper environmental legislation and infrastructure.

Wastewater effluents contain nutrients in many chemical varieties (ammonia, phosphates, nitrate, etc.), with a daily and seasonal variation in concentrations. The closer to the source of contamination, the higher the variations in contents will be (Martijn and Redwood, 2005). In agricultural nutrient management most of the time only macronutrients nitrogen (N), phosphorus (P) and potassium (K) are concerned, because deficiencies of these nutrients are more common than deficiencies of other macro- and micronutrients (Hilhorst and Muchena, 2000; Jones and Jacobsen, 2001). With respect to crop nutrient requirements, N and P are contained in undiluted untreated wastewater at levels of concern. K levels are generally below crop requirements (Feigin *et al.*, 1991; Martijn and Redwood, 2005). Irrigation with primary treated wastewater generally applies more nitrogen to the soil than is needed by agricultural crops (Crites *et al.*, 2000; Martijn and Redwood, 2005). Nitrogen and phosphorus overdoses affect the quality of certain crops, when leached from the soil to surface waters it may lead to eutrophication. Nitrates in drinking water can be hazardous to human health and nitrate is toxic to most fish and other aquatic species (Feigin *et al.*, 1991; Martijn and Redwood, 2005). Nutrient percolation to groundwater sources can be caused by excessive (mineral) fertilization, over irrigation of nutrient rich water, or a combination. Proper nutrient management is hard to achieve because adequate information on nutrient content is neither available nor forwarded to farmers. Martijn and Redwood (2005) mention several cases where farmers still use mineral fertilizers while irrigating with (un)treated wastewater. Long term effects of this habit must be considered carefully. Farmers often use wastewater as a source of water and not as a source of nutrients. As wastewater contains nutrient concentrations sufficient to at least partly meet crop nutrient requirements, irrigation could be helpful to remove nutrients to environmental standards.

Farmers that directly use wastewater for irrigation have their perceptions about the advantages and the disadvantages. Farmers who use wastewater indirectly often see their water resource as polluted and something negative (Durán *et al.*, 2003; Martijn and Redwood, 2005). Indirect use is strongly related to a lack of information on nutrient concentrations, what in its way is linked to a policy of unregulated wastewater disposal into surface waters.

To optimize the application of wastewater to agricultural crops as a means of wastewater treatment, designers can use crop selection. However, crop restriction is hardly ever favored by farmers as it will stop them to produce economically interesting crops. Crop selection therefore must be based on a combination of the quality of the wastewater, type of irrigation method, marketability of the crops, and the public acceptance of wastewater irrigated produce (Martijn and Redwood, 2005). Vegetables that are eaten raw are most controversial with respect to wastewater irrigation. However, these are the products that have to be fresh at the market and are therefore produced in the vicinity of the urban consumers. Therefore, and because of cash purposes, vegetables are a prime choice of (peri-)urban farmers (Martijn and Redwood, 2005).

The use of wastewater in peri-urban irrigated agriculture is not only build up from physical flows and infrastructure, but takes place within a societal context of diverse agricultural practices and governmental policies on land-use and water management. The socio-technical network of peri-urban irrigated agriculture and urban wastewater management is a dynamic area. In the view of Guy and Marvin (2001) it is important to see the interconnections of production and consumption in all infrastructure management. Wastewater production and agricultural use should therefore not be treated independently. When reviewing literature and engineering projects, the content of the term sustainable development is by far clear and totally different approaches of development are called sustainable. Therefore, it cannot be assessed whether urban wastewater management in itself is sustainable or not. Sustainability in itself is thus an empty category (Guy and Marvin, 2001; Werner *et al*., 2003). The social structures and institutional concepts of service delivery differ in each country, region and across infrastructure sectors. Sustainability can only be defined by the success of technological innovation to improve the environment within the social, economical and institutional context of the specific region.

With respect to the use of wastewater, integration is needed in two respects. First, for environmentally safe irrigation with water sources of poor quality in the peri-urban area, it is necessary to integrate agricultural water management into urban water management. Second, we are convinced that change towards sustainability should rely on an approach that considers infrastructural systems as part of *socio-technical* networks: the embedding of infrastructures in social and institutional contexts. The key to change is to be found in the dynamics of the interrelation of the physical and institutional aspects of water infrastructures, following a water chain approach (Huibers and van Lier, 2005).

Werner *et al.* (2003) describe several factors of unsustainability of the conventional sanitation and drainage system. First, in water prone areas the water quantity itself is a factor of unsustainability. The high water consumption of the conventional system in the long term can lead to irreversible overexploitation of the water resource. Second, there are high investment costs, energy use, and operation and maintenance costs. In most developing countries it is the costs of the conventional system that causes major problems to sustainability. Third, the ability of law enforcement, incomplete (by-)laws, non-existence of environmental laws/rules/regulations/policies, the ability and existence of working governmental environmental agencies, the ability of agencies to take responsibilities and to work together in a profitable way. Last, equal priority should be given to wastewater management as well as to water supply. Radical change is necessary in existing wastewater management strategies. Principles of chain management are well-known for many other industries are yet to be adopted by urban infrastructure management in general. Peterson *et al.* (2001) discuss strategies of stakeholders within the vertical supply chain. The strategies of the stakeholders are on the one extreme described as spot markets, in which individuals handle in their own interest, and on the other extreme the strategies of the stakeholders are described as vertical integrated, in which the stakeholders share benefits and information. As Werner *et al.* (2003) show that the conventional system is unsustainable it is safe to state that within urban wastewater management acting like spot markets is not profitable for the environment. For example, it is necessary that information on water quality is shared with farmers in order to adapt their nutrient management practices. Rethinking (waste)water management offers new understanding of the interrelationships between physical production and supply processes of urban wastewater and the changing social and physical dynamics of (peri-)urban wastewater consumption.

Materials and Methods

Research was done in Đong Du commune in the peri-urban district Gia Lam in Hanoi. Đong Du is located east of the Red river and is bounded by the river Cau Bay to the west. Agriculture depends, except for the wet season, on the district irrigation system which takes up water from Cau Bay River. Cau Bay river receives domestic and industrial wastewater effluents. The irrigation system is originally designed for the sole purpose of rice cultivation. However, since the *doi moi,* farmers produce more cash crops. Farmers in Đong Du have specialized themselves in the production of herbs, especially spiny coriander, *Eryngium Foetidum (L.)*. The process of urbanization resulted in the Thanh Tri bridge project, several households in Đong Du lost land due to land acquisition. The area is under further urban construction pressure as two main roads are planned to be constructed in the near future.

In Đong Du farmers apply mineral fertilizers to their crops. Although the irrigation system itself is formal and planned, the use of wastewater is better to be described as indirect and unplanned, because the occurrence of wastewater is not in the design of the system and there are no formal agreements between farmers and the government to use the wastewater. The combination of mineral fertilizer application and the indirect unplanned use of wastewater for irrigation is expected to result in excessive application of nutrients to downstream terrestrial and aquatic ecosystems. The indirect unplanned use suggests that farmers have a lack of information on water quality from institutional organizations. Therefore it is expected that farmers apply unnecessary excessive amounts of fertilizers to their crops. The indirect unplanned use of wastewater also shows that the governmental system of Hanoi municipality has not integrated peri-urban agricultural water management into its urban (waste)water management system. It is expected that the stakeholders of the wastewater supply chain act as spot markets, information is not shared among stakeholders and relationships are short term. By integrating agricultural water use in the urban (waste)water management system, creating vertical integration, the use of wastewater will be more formal. This allows farmers and government to communicate openly with each other on water quality characteristics and improve environmentally safety of peri-urban agriculture.

Information on irrigation water quality was received from the SEARUSYN[4] project. Research was conducted at field level through 25 open semi-structured interviews with farmers and a group discussion with 15 farmers of Đong Du. During these interviews information was received on fertilizer application and the awareness of farmers of water quality, urbanization processes, crop quality, health issues, water quantity, marketability, institutional aspects and future perspectives. The water quality data and fertilization practices were compared and analyzed by the Microsoft Excel based software model *Optimal nutrient management*, developed by students of Wageningen University. The input of the model includes polluted water characteristics, crop water requirements, crop nutrient requirements, growing stages, soil properties and water management. The output of the model shows the benefits of using nutrient rich waters for irrigation to save on extra fertilizer inputs (Dubale *et al.,* 2005, unpublished).

[4] South East Asian Rural Urban SYNergy, EU 5th Framework INCO2 funded research project. http:/www.searusyn.org

To find out how peri-urban irrigated agriculture is integrated in urban water management a number of qualitative interviews with officials were done at local level (Đong Du), district level and municipal level. The stakeholders were defined based on an institutional system analysis by Luan and Minh (2005) on peri-urban agricultural management.

Results and Discussions

For the calculation of nutrient management the nutrient content of the irrigation main canal was used. Water samples were taken in the months of March, June and October 2005. The data from the water samples were compared to the monthly rainfall data of Hanoi, obtained from the CLIMWAT database of FAO. Using these figures, estimates were made for the nutrient concentrations in the different months of the year.

The *Optimal Nutrient Management* model uses crop water requirements to calculate the amount of nutrients that can be saved per growing season. Evapotranspiration is therefore an important input. For the input ET_0, it was chosen to average monthly data into an ET_0 for the growing season. Other data were already available in the model. The results from the model are shown in Figure 1. The *Optimal Nutrient Mangement* model has input data for the several major produced crops around the world. For spiny coriander it was necessary to use the manual input mode of the model. Because of a lack of available input data of spiny coriander , data of alfalfa was used. Alfalfa and spiny coriander both have high vegetative growth and are both perennial crops that can be harvested multiple times during that period. However, alfalfa is able to fix nitrogen and therefore the nitrogen requirement figures for alfalfa will be less then for spiny coriander. For P and K it is expected that the two crops show comparable results. Estimates of nitrogen were made according to other crops with major vegetative growth available in the model.

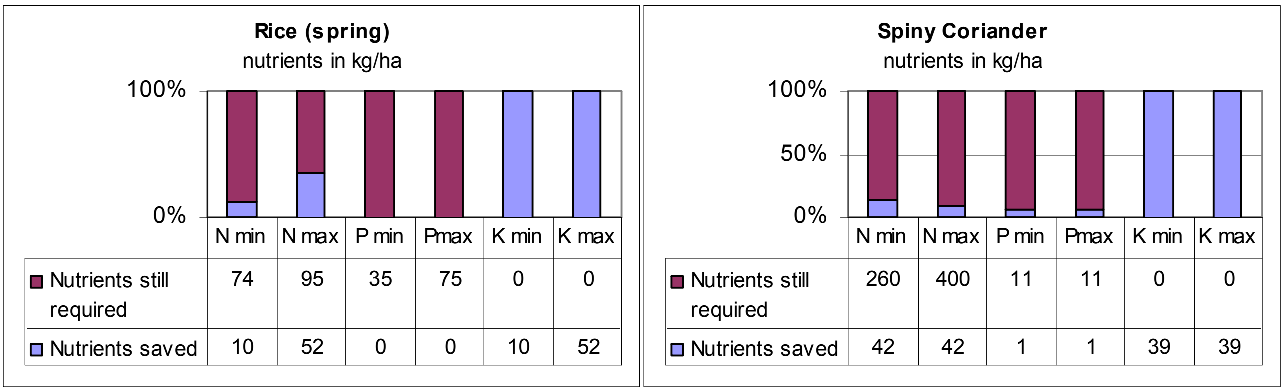
Some of the results are shown in Tables 1 and 2 and Fig. 1. The results show that even with weakly polluted irrigation water considerable amounts of fertilizers can be saved.

Table 1. Nutrient concentration estimates irrigation canal Đong Du (mg/l)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nitrogen	15	15	15	13	7	3.6	1.5	0.8	4	8.6	13	15
Phosphorus	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Potassium	15	15	15	13	7	0.5	0.5	0.5	4	9.9	13	15

Table 2. Fertilizer gifts by farmers per cropping season: average and range (kg/ha)

	Average gift			Range gift		
	N	P	K	N	P	K
Rice	275	160	80	80-1000	80-600	0-350
Maize	275	80	0	100-500	0-220	0-80
Spiny coriander	1000	275	25	600-2000	0-500	0-130



Rice (spring), nutrients in kg/ha

	N min	N max	P min	Pmax	K min	K max
Nutrients still required	74	95	35	75	0	0
Nutrients saved	10	52	0	0	10	52

Spiny Coriander, nutrients in kg/ha

	N min	N max	P min	Pmax	K min	K max
Nutrients still required	260	400	11	11	0	0
Nutrients saved	42	42	1	1	39	39

Figure 1. Results *Optimal Nutrient Management* model, for rice and spiny coriander, showing nutrient savings and requirements per growing season (kg/ha)

The nutrient inputs were compared with the nutrient requirements of Fig. 1. All cases show excessive application of nitrogen. Only for maize phosphorus shows a deficit when compared with the average input of phosphorus, however when compared with the maximum input surpluses can go up to 100 kg/ha per cropping season. In contrast to what is mentioned by Feigin *et al.* (1991) K levels in the polluted water are high enough to fulfill crop demands of maize, rice and spiny coriander. The fertilizer application surpluses and the high ranges between farmers of fertilizer application show that there is not a common knowledge of proper nutrient management in this area.

1. Farmers' perceptions on irrigation water

Most of the farmers in Đong Du perceive the water quality of the communal irrigation system as bad. It has more disadvantages than advantages. Although most do not think that the water harms crop quality too badly. Only a few mentioned fertile components in the irrigation water as an advantage of the water resource, but related it to fertile alluvial sediments rather than to nutrients from domestic wastewater.

Although urbanization processes reduced the irrigation water quality it did improve market accessibility. The area produces more cash crops every year and farmers specialized themselves in the production of spiny coriander of which market demands still grow. Due to low water quality sometimes yellow stains occur on spiny coriander leaves. It is thought to be related to high iron levels in the water. Low quality of spiny coriander leaves reduces market prices. Therefore, farmers in Đong Du cut of the yellow stains so the leaves appear to be of high quality. Farmers wash their crops in the irrigation canals before bringing their crops to the market. These two habits show that the awareness of farmers about food quality is rather low.

Most farmers perceive problems that are related to the functioning of the irrigation system. The system was originally solely designed for rice production. The lack of maintenance and the scattering of small plots with different kind of crops result in problems in water delivery.

There is no structured governmental education program for farmers to improve their skills. About 50% of the households have a member that followed some kind of course on fertilization practices. Farmers mention their neighbors to be important information sources on nutrient management. It is rather strange that the ranges in fertilizer application between farmers are so high.

The unplanned indirect use of wastewater in peri-urban irrigated agriculture in Hanoi, the lack of knowledge on nutrient management, the absence of governmental education programs shows clearly that agricultural water use is not integrated into the Hanoi urban (waste)water management system.

2. Institutional cooperation

Hanoi has a special municipal status. Hanoi is subjected to the state management system and has therefore a four leveled vertical administrative management system. Within this vertical system there are horizontal relationships between different departments; municipal department, district departments and communal offices. Within these vertical and horizontal relationships there can be a variety of crossing relationships, these can be very complex and formal and informal (Luan and Minh, 2005).
Horizontal coordination is very difficult or is done ineffectively due to the separation of each agency/organization in performing their tasks. There is no coordinating body that is responsible for managing entire processes (Luan and Minh, 2005). All the departments mention that a lack of cooperation is a major problem in decision making and legislation enforcement. At this moment responsibilities of the different departments are not only scattered, but as well unknown among the different stakeholders. It is clear that Hanoi municipality makes a distinction between peri-urban agricultural management and urban management. The department of Agriculture and Rural Development is responsible for peri-urban sanitation, while the Department of Environment and Natural Resources mentions that they are the only institution to receive the city's master plan in wastewater treatment. Although the departments say that urban agriculture should be integrated in urban water management, this shows that Hanoi municipality does not integrate peri-urban areas in urban management at this moment.

The master plan includes that in the future the urban wastewater infrastructure will be improved. Currently, the 10 years project of wastewater treatment is being implemented. It is divided into 3 phases: flooding prevention, building of adjustment lakes for wastewater sedimentation by 2010, and lastly wastewater treatment (2010-2020). It is expected by the departments that the organizational management will also be improved, although it will be a challenge.

None of the interviewed municipal departments of Hanoi considered wastewater, or polluted surface water, as a good source for irrigation. Nobody would recommend farmers to use it. Further several interviewed officials denied the use of wastewater in irrigated peri-urban agriculture. It is therefore unlikely that the master plan will include wastewater reclamation schemes for (peri-)urban irrigated agriculture. Wastewater reclamation schemes can reduce treatment costs and therefore be of interest for wastewater treatment systems in cities in developing countries. The costs of the master plan are expected to be about 375 million US$ and daily maintenance costs are expected to be 0.13 million US$ a day, that will be 30 times higher then the current maintenance costs. This has to result in 100% wastewater treatment by treatment plants.

Farmers mention that there are no structured education programs on nutrient management. Information on water quality, if at al available, does not reach farmers, but if it would, they would not be able to use it. The head of the farmers union and vice-chairman of the farmers cooperative mentioned that their priority is implement orders from higher leveled authorities. They are able to express their opinions and to address problems a few times a year. However, it is questionable if these opinions will reach the top and will be implemented downwards again. If they do, it is a time consuming process to get the problems solved at field level again. Cooperation only exists when necessary, like during periods of flooding. It is likely that the relations between municipal, district level and communal and farmers level will not be changed. None of the interviewed officials mentioned farmers, or the farmers union and cooperative, as stakeholders of urban (waste)water management nor peri-urban irrigated agriculture. Comparing these results to the unsustainability factors described by Werner *et al.* (2003) it is questionable whether within this growing city and increasing water consumption the set targets can be reached within a scattered governmental network.

As mentioned above rethinking can offer new understanding of the interrelationships between physical production and supply processes of urban wastewater and the changing social and physical dynamics of (peri-)urban wastewater consumption. It is mentioned above that principles of chain management that are well-known for many other industries are yet to be adopted by urban infrastructure management in general. Likewise institutional change within the Hanoi municipal system is needed to accept and to facilitate that wastewater is used in (peri-)urban irrigated agriculture; that 'problems' created by urban factors can be solved by connecting peri-urban agriculture to urban (waste)water management. Cooperation between stakeholders that manage wastewater production (municipal and district departments of Natural Resources, Environment and Land, Public Works, and Urban Planning), stakeholders that manage wastewater alteration (municipal and district department of Agriculture and Rural Development, Irrigation Water Companies, and the farmers' cooperatives and unions) and farmers can lead to environmentally safe peri-urban agriculture. In between there are stakeholders responsible for transport and logistics (department of Public Works, Irrigation Companies). In this view the environment is the end consumer that demands an environmentally safe product. The stakeholders in Hanoi act like individual links in the chain. Therefore, the stakeholders show characteristics that in supply chain theories are headed under "invisible hand coordination" (Peterson *et al. 2001)*. They only create short term relationships with each other, act out of self interest and most important there is limited information sharing among the stakeholders in the chain. Vertical integration of peri-urban agriculture is necessary. When departments would work together to a common goal, costs could be saved not only in treatment, but as well on nutrient inputs at field level. Economic and environmental benefits can therefore be incentives to integrate the use of wastewater in peri-urban agriculture in the chain of urban (waste)water management. The integration can be done in many forms and total vertical integration is maybe not the most sustainable solution. This explorative study does not and can not reveal whether Hanoi should introduce stakeholder platforms to facilitate the departments or create a new governing body for urban water management in which agricultural water is integrated. For that social, economical and environmental factors have to be compared. However, when the stakeholders would improve their cooperation and communication within the water chain and work together to a common goal, costs could be saved and pollution reduced. Economic and environmental benefits can therefore be incentives to integrate the use of wastewater in peri-urban agriculture in the chain of urban (waste)watermanagement.

Conclusions

Until this moment the peri-urban irrigation sector and the urban water management sector co-existed independently from each other. With urbanization processes going on these two sectors will be getting more and more integrated. Urban construction will go on, but farmers specializing themselves (integrating into urban market demand) and making decent incomes will be getting harder to be bought out of their land (Van den Berg *et al.,* 2005). Integrating peri-urban agriculture into urban water management could give these farmers an important role in the urban ecosystem.

For environmentally safe nutrient management farmers need to have improved access to clear and trustable information sources. Only with improved knowledge and trust in the information received on irrigation water quality farmers will take the risk to reduce and adjust their fertilizing practices on the basis of nutrient levels contained by the irrigation water.

Open space (peri-)urban agriculture can play an important role in growing cities, not only in closing nutrient cycles, but as well in urban landscape. Therefore it is necessary that (peri-)urban irrigated agriculture is recognized as an integral part of urban water management.

In Hanoi it is necessary that governmental bodies will cooperate to get information to the farmers at field level and to facilitate the management of a whole chain of urban water and nutrients. Extension services should provide information and training to local farmers to improve the impact of agriculture on the environment.

Rethinking urban wastewater supply and peri-urban nutrient demand can lead to innovative ideas in wastewater management and the functions of peri-urban agriculture in the urban environment. Thinking beyond conventional ideas of urban water management and peri-urban agriculture in general, and in reference to Hanoi in particular could reduce costs in wastewater treatment, reduce inputs in fertilizers and improve the urban ecosystem.

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