Research Journal of Applied Sciences, Engineering and Technology 7(1): 77-82, 2014
DOI:10.19026/rjaset.7.223
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: January 27, 2013 Accepted: March 08, 2013 Published: January 01, 2014

Research Article

The Low-Carbon Construction and Operation Technologies of Water System in the Residential District of Mountainous City

Chai-Hong Xiang, Yang-Shi Qi, He-Qiang and Zhang-Ting Ting
Key Laboratory of Three Gorges Reservoir Region's Eco-Environment, Ministry of Education,
Chongqing University, Chongqing, 400045, China

Abstract: In order to achieve the low-carbon construction and operation in the water system of mountainous residential district, the key link of Greenhouse Gas (GHG) emission of water system in mountainous residential district was studied and GHG emission was analyzed and quantified. According to the key link of GHG emission, trying to transform the traditional mode of long distance transportation of the drainage system and the terminal sewage biological treatment to reduce the GHG emission, therefore, several low-carbon technologies in the mountainous residential district were put forward, including: the low-carbon technology of controlling water supply pressure to limiting flow, the technology of low-carbon and ecological treatment of reclaimed water and carbon sequestration technology, the ecological technology of controlling and reducing the source of rain water in the steep slope residential district and the technology of recycling use of the non-traditional water source to reduce GHG emission from water system in mountainous residential district. By quantification the reduction of GHG emission, the results shows that, the low-carbon construction and operation technologies of water system in mountainous residential district, achieved more than 30% reduction of GHG emission from water system in mountainous residential district.

Keywords: Greenhouse gas, low-carbon, mountainous city, residential district, water system

INTRODUCTION

Because of the great difference in topography in the mountainous city, there are some problems in the water system of mountainous residential district, such as wide variation of water supply pressure in water supply system, which will lead to serious overpressure leaving flow and enormous waste of water resources; rapid discharge and great water flow velocity in drainage system, which will increase the investment and operating costs in municipal drainage system; great energy consumption of pumps in water supply and drainage system. Therefore, compared with the water system in ordinary residential district, both energy consumption and GHG emission are much higher.

With the purpose of the sustainable development of the human settlements in mountainous regions and realization of the ecological and low-carbon in mountainous residential district, it is necessary to adopt feasible measures to reduce GHG emission from water system in mountainous residential district. The GHG emission from water system has attracted great attention of worldwide scholars; as a result, massive researches about reduction of GHG emission from water system have being conducted.

Centralized water supply and wastewater services; decentralized water supply and wastewater systems; direct emission from wastewater treatment and handling; and urban water supply reservoirs are all contributors to energy and GHG emission for urban water supply and wastewater services over the long-term (Murray *et al*., 2011).

In the UK, significant quantities of energy, amounted to more than 8 billion KWh of energy ranging from 2007 to 2008, are used to treat water to potable quality, deliver it to consumers and to process and dispose of wastewater, leading to emission of about 5 million tons of GHG (Water, 2009).

By the appropriate strateges, it is possible to reduce the GHG emission as well as operational costs (Xavier *et al*., 2011). Based on definitions of the physical configuration or operating characteristics, an approach which distinguished between plants at high nitrite concentration or low nitrite concentration would be put forward. Finally, the appropriate strateges can be determined (Jeffrey *et al*., 2010). In the view of reducing the GHG emission from water treatment, aerobic process is suitable for very low strength wastewaters (less than 300 mg/L BOD). At higher strengths, anaerobic wastewater treatment is more favorable (Cakir and Stenstrom, 2005; Greenfield and Batstone, 2005).

Corresponding Author: Chai-Hong Xiang, Key Laboratory of Three Gorges Reservoir Region's Eco-Environment, Ministry of Education, Chongqing University, Chongqing, 400045, China, Tel.: 18623048087

Table 1: Specifics of GHG emission from each water subsystems of mountain residential district

Subsystems	Direct emission sources	Indirect emission sources	Key factors	Quantitative methods
Water supply system		Water supply energy consumption	Water quantity and water pressure	Energy conversion
Wastewater system		Transforming and lifting the energy consumption	Water quantity	Energy conversion
Rainwater system		Transforming and lifting the energy consumption	Water quantity	Energy conversion
Reclaimed water system	Organic matter degration	Processing energy consumption and medicine consume	Water quantity and pollution load	Energy conversion and treatment quantity of pollution conversion

In wastewater treatment plants, reduction of GHG emission relate to energy consumption and the biomass sequestration and biogas energy recovery in wastewater treatment can be a net carbon sequestration, which in turn furthers the reduction of GHG emission (Diego and Stenstrom, 2008; BaniShahabadi *et al*., 2009). And the GHG emission from final sludge management in treatment plants should be taken into account as well (Margarita and Scarlette, 2008).

Nevertheless, a number of recent studies have confirmed that significant proportions of water-related energy (96%) and the associated GHG emission (87%) are attributed to water consumption in households. Many composite strategies for reduction of GHG emission have been performed, whilst saving water do not necessarily save energy or reduce GHG emission (Fidar *et al*., 2010). Water demands are related to GHG emission of water supply services as well as energy consumption (Nie, 2009). Large amount of energy is consumed and GHG is produced during the processes of construction and operation in water system. Consequently, there is great potential to save energy and reduce GHG emission (Zhang *et al*., 2010; Chai *et al*., 2011).

Due to the particularity of mountainous city, it is difficult to plan and design the water system in mountainous residential district. The key points to design this water system are still the pressure of district water supply (Wang, 2006) and energy dissipating of drainage system (Ma, 2005).

Through the analysis of the sources of GHG emission form water system, worldwide scholars put forward various schemes for low-carbon construction and operation in water system and deemed that water-saving is an important pathway of reducing GHG emission. So far, the research about reduction of GHG emission from water system in mountainous residential district has not been reported yet. However the energy consumption and GHG emission of the water system in mountainous residential district are much higher than the ordinary residential district. So it is significantly to study the reduction of the GHG emission from water system in mountainous residential district.

This research aims at reducing the GHG emission from water system in mountainous residential district. The key factors of GHG emission from water system in mountainous residential district are determined and the sources of GHG emission are analyzed. According to the key factors of GHG emission, several low-carbon technologies for water system in the mountainous residential district are put forward to cut down the GHG emission, finally the GHG emission from water system in mountainous residential district and the reduction of GHG emission by taking the low-carbon construction and operation technologies are quantified.

RESEARCH METHODS

GHG emission quantitative methods: The water-related processes in mountainous residential district include: municipal water supply, water consumption in residential district, discharge of wastewater and reclaimed water treatment.

The quantitative methods depend on the two emission sources of GHG: direct emission sources and indirect emission sources. Direct emission sources are production activities which cause GHG emission inside and indirect emission sources are production activities which cause GHG emission outside (e.g., external electric power, heat or the steam consumption). According to the guidance Greenhouse gases-Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emission and removal (ISO14064-1) (IPCC, 2006), identification the sources of GHG emission of each water subsystems, determined the key factors and quantitative methods.

Table 1 illustrates the specifics of emission sources, key factors and quantitative methods of GHG emission in each water subsystems.

Deciding the coefficients in each water subsystems of GHG emission and water quantity: In accordance with the quantitative method of energy conversion mentioned in Table 1, then combined with the corresponding relation between amount of energy consumption and water quantity in water supply system, wastewater system and rainwater system, the coefficients of GHG emission and water quantity were decided.

Table 2: GHG emission coefficients in each water subsystems of mountainous residential district

GHG emission coefficient	Water supply system	Drainage system	Reclaimed water system
Indirect emission (kg/m^3)	0.40	0.30	0.10-0.25
Direct emission (kg/m^3)	—	—	0.10-0.55

Reclaimed water treatment can take physico-chemical process, biochemical process and ecological process. The energy consumption of these processes is different. Similarly, according to the amount of energy consumption and treatment quantity of pollution load during these processes of reclaimed water treatment, the coefficients of GHG emission and water quantity in different processes were determined.

Caculating the reduction of GHG emission in water system of mountainous residential district: When the reduction measures were taken, the key factors and coefficients of GHG emission would be diminished. The decrement of key factors was calculated by the actual statistics in the mountainous residential district or depended on the comparison between the reduction measures and traditional modes, the coefficients of GHG emission in reclaimed water system were depended on the specific processes. Finally, the reduction of GHG emission was figured out.

Caculating the reduction of GHG emission in urban water system: Due to the water quantity is the key factor of GHG emission as well in urban water system, the GHG emission would be cut down after the reduction measures were taken. According to the amount of energy consumption and treatment quantity of pollution load during the processes of water and wastewater treatment in urban water system, the coefficients of GHG emission and water quantity were determined. The decrement of key factors was depended on the reduction measures. Finally, the reduction of GHG emission in urban water system was worked out.

RESULTS AND DISCUSSION

Quantitative method of GHG reduction: Table 2 shows the corresponding relation between GHG emission and water quantity in each water subsystems of mountainous residential district and the GHG emission is measured by mass equivalent of CO_2.

While the GHG emission coefficients of different reclaimed water treatment process are different and the difference is showed in Table 3.

Table 4 shows the comparison of GHG key factors between rainwater controlling at source on the base of low impact development and direct discharging.

Table 5 shows the corresponding relation between GHG emission and water quantity in each urban water subsystems.

Therefore preliminary calculation of the reduction rate of GHG emission is possible. The Formula of GHG emission from water system in mountainous residential district is showed below:

Table 3: GHG Emission coefficients of different reclaimed water treatment processes

GHG emission Coefficient	Physico-Chemicalprocess	Biochemical Process	Ecological Process
Indirect emission (kg/m^3)	0.25	0.20	0.10
Direct emission (kg/m^3)	0.55	0.30	0.10

Table 4: Comparison of GHG key factors between rainwater controlling and direct discharging

GHG key factors	Rainwater controlling at source	Rainwater direct discharging
Peak discharge	45%	100%
Pollution load	20%	100%

Table 5: GHG emission coefficients in each urban water subsystems

GHG emission coefficient	Water treatment	Waste water treatment
Indirect emission (kg/m^3)	0.50	0.65
Direct emission (kg/m^3)	—	0.50

$$GHG_0 = IF_1Q_{01} + IF_2Q_{02} + IF_3Q_{03} + (IF_{04} + DF_{04})Q_{04} \quad (1)$$

When the low-carbon construction and operation technologies are taken, the Formula of GHG emission from water system is showed below:

$$GHG_L = IF_1Q_{L1} + IF_2Q_{L2} + IF_3Q_{L3} + (IF_{L4} + DF_{L4})Q_4 \quad (2)$$

According to the Formula (1) and Formula (2), the reduction rate of GHG emission can be figure out:

$$R = (1GHG_0/GHG_L) \times 100\% \quad (3)$$

In addition, the decrement of GHG emission from urban water system caused by low-carbon construction and operation technologies of water system in mountainous residential district can be figured out as well, which is showed in Formula (4):

$$GHG_D = IF_5(Q_{01}-Q_{L1}) + (IF_6 + DF_6)(Q_{02}-Q_{L2}) + (IF_6 + DF_6)(Q_{03}-Q_{L3}) \quad (4)$$

GHG_0 = Annual GHG emission of water system in mountainous residential district, kg/a
GHG_L = Annual GHG emission of water system in mountainous residential district when the low-carbon construction and operation technologies are taken, kg/a
GHG_D = Decrement of GHG emission from urban water system caused by low-carbon construction and operation technologies of water system in mountainous residential district, kg/a
R = Reduction rate of GHG emission of water system in mountainous residential district when the low-carbon construction and operation technologies are taken, %

IF_1 = Coefficients of GHG indirect emission from water supply system in mountainous residential district, kg/m^3
IF_2 = Coefficients of GHG indirect emission from wastewater system in mountainous residential district, kg/m^3
IF_3 = Coefficients of GHG indirect emission from rainwater system in mountainous residential district, kg/m^3
IF_{04} = Coefficients of GHG indirect emission from reclaimed water system in mountainous residential district, kg/m^3
DF_{04} = Coefficients of GHG direct emission from reclaimed water system in mountainous residential district, kg/m^3
IF_{05} = Coefficients of GHG indirect emission from water treatment in urban water system, kg/m^3
IF_{06} = Coefficients of GHG indirect emission from wastewater treatment in urban water system, kg/m^3
DF_{06} = Coefficients of GHG direct emission from wastewater treatment in urban water system, kg/m^3
IF_{L4} = Coefficients of GHG indirect emission from reclaimed water system in mountainous residential district when the low-carbon construction and operation technologies are taken, kg/m^3
DF_{L4} = Coefficients of GHG direct emission from reclaimed water system in mountainous residential district when the low-carbon construction and operation technologies are taken, kg/m^3
Q_{01} = Water consumption in mountainous residential district, m^3/a
Q_{02} = Quantity of wastewater in mountainous residential district, m^3/a
Q_{03} = Quantity of rainwater in mountainous residential district, m^3/a
Q_4 = Treatment scaleof reclaimed water in mountainous residential district, m^3/a
Q_{L1} = Water consumption in mountainous residential district when the low-carbon construction and operation technologies are taken, m^3/a
Q_{L2} = Quantity of wastewater in mountainous residential district when the low-carbon construction and operation technologies are taken, m^3/a
Q_{L3} = Quantity of rainwater in mountainous residential district when the low-carbon construction and operation technologies are taken, m^3/a

Reduction measures of GHG emission:

- **Controlling water supply pressure to limit flow:** Both water pressure and water quantity are the key factors of GHG emission from water supply system in mountainous residential district. On the premise of meeting the demand of the water pressure in mountainous residential district, the technology of controlling water supply pressure to limit flow will be designed reasonably according to the topographic feature of the designed location. This technology will help be control the water pressure in the reasonable range effectively, unnecessary water loss will be avoided, the life cycle of water supply accessories will be extended and energy consumption and operation cost of water supply system will be reduced. Meanwhile, the GHG emission from water supply system in mountainous residential district will be reduced inevitably.

- **Low-carbon and ecological treatment of reclaimed water:** From Table 1, GHG emission sources of reclaimed water system are energy consumption and organic matter degradation. Water quantity, energy consumption and nutrients as resources to recycle need to be considered in water treatment processes, rather than wastes to separate. Consequently, constructed wetlands may be an appropriate solution for resource recovery and reducing GHG emission (Valerie *et al*., 2011). As a result, choosing low-carbon reclaimed water treatment process and producing carbon sequestration by plants can reduce GHG emission. The GHG emission coefficient varies among different reclaimed water treatment processes and Table 3 illustrates that the emission coefficients of ecological treatment process is the lowest.
  The ecological treatment of reclaimed water adopts the Adsorption-Biodegradation process, enhanced biological flocculation process and ecological process (e.g., constructed wetlands).It not only reduce the GHG emission from reclaimed water system, but also transforms organic to the utilizable clean energy which will benefit and push forward the replacement of fossil fuel by the recovery and reuse of biogas for energy generation. Accordingly, carbon sequestration will be formed during the ecological treatment of reclaimed water because plants offset part of the direct GHG emission.

- **Controlling and reducing rainwater source of the sites with steep slope:** The key factors of GHG emission from rainwater system in mountainous residential district are peak flow and pollution load of rainwater. From Table 4, the technology of controlling the source of rainwater will reduce the peak flow and pollution load. Therefore, it is the principal pathway of low-carbon construction and operation of rainwater system in mountainous residential district.

The ecological technology of controlling and reducing the source of rainwater of the sites with steep slope includes runoff detention by vegetation on contour line and tiny terrain modification, runoff storage and purification by concave ground and the rainwater stranded ecological treatment by the roof of building, rain garden and ecological lake body.

Through this technology, the strong hydraulic flushing and intensive load of drainage system in short time will be cut down, so will the peak flow and pollution load of rainwater. Consequently, the GHG emission from drainage system in mountainous residential district will be reduced. Besides, the plants in ecological treatment facilities will absorb and fasten the GHG emission.

- **Recycling use of the non-traditional water source:** The recycling use of the non-traditional water source is also a feasible measure of low-carbon construction in water system in mountainous residential district. The traditional rainwater collection facilities will be replaced by artificial lake which can realize the fundamental treatment of the rainwater to meet the standard of reclaimed water. So that the GHG emission from the traditional wastewater collection facilities will be reduced and the GHG emission from the traditional process of water collection, purification, distribution and transmission will be reduced as well.

Specific practice: The specific practice takes a mountainous residential district as example. Total construction area is 297000 m^2, the number of residents reaches 2100 and the water facilities are complete.

In this mountainous residential district, the annual municipal water consumption is 546000 tons, the daily processing scale of reclaimed water is 480 tons, the annual municipal wastewater quantity is 265000 tons and the annual municipal rainwater quantity is 110000 tons. According to Formula (1), the annual GHG emission from water system are 470 tons.

Through the low-carbon construction and operation technology of water system, the GHG emission factors are well controlled, the coefficient meets the minimum, the water saving rate up to 37.8%, the annual municipal water consumption of this residential district decreases to 202000 tons, the annual municipal wastewater quantity reduces by 100000 tons, the annual municipal rainwater quantity decreases to 50000 tons and the daily processing scale of reclaimed water is invariable. According to Formula (2) and Formula (3), calculate the annual GHG emission from water system are148 tons and reduction rate of GHG emission can reach to 31%. In addition, from Formula (4), 365 tons' GHG emission from urban water system will be cut down due to the water-saving strategies annually.

CONCLUSION

Through the analysis of the point from which the GHG emission mainly occur in water system in mountainous residential district, the quantitative method of GHG emission is figured out and low-carbon construction and operation technologies of water system in mountainous residential district which corresponds with the topographic feature of mountainous city are put forward. The low-carbon construction and operation technologies are consist of the low-carbon technology of controlling water supply pressure to limit flow in mountainous residential district, the technology of low-carbon and ecological treatment of reclaimed water and carbon sequestration technology in mountainous residential district, the ecological technology of controlling and reducing the source of rain water in the residential district with steep slope and the technology of recycling use of the non-traditional water source. And the integration of the system and space of technology does not only realize the reduction rate of GHG emission by more than 30%, but also changes the traditional urban drainage system mode with long-distance transporting and terminal wastewater treatment and reduces the GHG emission from urban water system in mountainous city.

ACKNOWLEDGMENT

The study was funded by the National Key Technology R&D Program in the 12^{th} Five year Plan of China (Grant No.2011BAJ07B03).

REFERENCES

Banishahabadi, M., L. Yerushalmi and F. Haghighat, 2009. Impact of process design on Greenhouse Gas (GHG) generation by wastewater treatment plants. Water Res., 43: 2679-2687.

Cakir, F.Y. and M.K. Stenstrom, 2005. Greenhouse gas production: A comparison between aerobic and anaerobic wastewater treatment technology. Water Res., 39: 4197-4203.

Chai, H.X., W. Yinghua and X. Haiyan, 2011. Water conservation: Construction and operation of management and technology systems for greencampus. Environ. Eng. Manage. J., 7: 931-936.

Diego, R. and M.K. Stenstrom, 2008. The carbon-sequestration potential of municipal wastewater treatment. Chemosphere, 70: 1468-1475.

Fidar, A., F.A. Memon and D. Butler, 2010. Environmental implications of water efficient micro components in residential buildings. Sci. Total Environ., 408: 5828-5835.

Greenfield, P.F. and D.J. Batstone, 2005. Anaerobic digestion: Impact of future greenhouse gases mitigation policies on methane generation and usage. Water Sci. Technol., 52: 39-47.

IPCC, 2006. Greenhouse gases-Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emission and removal. ISO 14064-1.

Jeffrey, F., D. De Haas and Z.Y.P. Lant, 2010. Nitrous oxide generation in full-scale biological nutrient removal wastewater treatment plants. Water Res., 44: 831-844.

Ma, N., 2005. Application of grid type energy dissipater in sewerage system of mountainous city. China Water Wastewater, 5: 54-58. (In Chinese with English Abstract)

Margarita, P. and L.G. Scarlette, 2008. Application of strategies for sanitation management in wastewater treatment plants in order to control/reduce greenhouse gas emission. J. Environ. Manage., 88: 658-664.

Murray, R.H., J. West, B. Sherman, J. Lane and D. De Haas, 2011. Long-term trends and opportunities for managing regional water supply and wastewater greenhouse gas emission. Environ. Sci. Technol., 45: 5434-5440.

Nie, M., 2009. Attached great importance to the development of low-carbon water sector. Constr. Sci. Technol., 23: 63-64. (In Chinese)

Valerie, J.F., J.R. Mihelcic and J.S. Gierke, 2011. Life cycle assessment of vertical and horizontal flowconstructed wetlands for wastewater treatment considering nitrogen and carbon greenhouse gas emissions. Water Res., 45: 2073-2081.

Wang, P., 2006. Programming practices of urban water supply network of the Yangtze gorges reservoir region. China Water Wastewater, 10: 36-39. (In Chinese with English Abstract)

Water, U.K., 2009. Sustainable water. State of the Water Sector Report, Water UK.

Xavier, F.A., L. Corominas, L. Snip and P.A. Vanrolleghem, 2011. Including greenhouse gas emission during benchmarking of wastewater treatment plant control strategies. Water Res., 45: 4700-4710.

Zhang, C., C. Yan, T. Xuejun and S. Xiao, 2010. Discussion on greenhouse gas generation and reduction strategies in urban wastewater system. Water Wastewater, 36: 29-33. (In Chinese with English Abstract)