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ECOLOGICAL COMPENSATION SYSTEM AND COMPENSATION EFFICIENCY MEASUREMENT OF RIVER BASIN: A CASE FROM CHINA

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ABSTRACT

River basin ecological compensation is a kind of interest-driven mechanism, encouragement mechanism and coordination mechanism of basin water resources protection and ecological environment construction, and its implementation effect is of great significance to basin economic development and environmental protection. In this paper, the ecological compensation of basin water resources in China is taken as the research object. Based on the research of the current situation and concrete practice of ecological compensation mechanism in China, an index system of ecological efficiency measurement of water resources in river basins is established in this paper, and the demand of water resources ecological compensation system in China is analyzed. Finally, the author puts forward the countermeasures to promote the balanced and balanced development of the river basins area.

Keywords: River basin water resource; ecological compensation system; efficiency.

1 INTRODUCTION

Liquidity makes river basin upstream and downstream form a tight community. Owing to the difference of geographical location, there is often an imbalance in the distribution of benefits between upstream and downstream of river basin. Upstream areas such as water source areas will lose a lot of opportunities for economic development due to the implementation of strict environmental protection measures and standards. While the downstream areas may be free to occupy the economic interests and ecological benefits spilling over the upstream areas' water resources and environmental protection. Nearly one-third of China's land area is distributed in 10 major river basin areas, including thousands of rivers of various sizes. The unbalanced distribution of the economic benefits of the river basin has also seriously hindered China's environmental protection and regional coordinated development.

As a new type of environmental management methods, ecological compensation has made remarkable achievements in the practice of domestic and foreign applications for protecting and sustainable use of ecosystem services and regulating various interests in ecological environment protection. The ecological compensation of river basins is based on river basin, and the balance between water using benefit of water using main body and sewage disposing main body in the economic system during the process of basin development is coordinated with the relationship between water use and water environmental protection. Contradictions, has now become the restoration and protection of ecological environment within the basin an important measure.

At present, China has not set up a sound river basin ecological compensation system. Although some practices have been carried out in some river basins, some problems still need to be systematically sorted out and analyzed in this paper. Measuring the efficiency and problems of specific compensation measures, and then improving the ecological compensation system of river basin water resources and promote the coordinated development of river basin.

2 A SUMMARY OF THE RESEARCH STATUS AT HOME AND ABROAD

2.1 River basin ecological compensation concept

Ecological compensation is a concept integrated by interdisciplinary research of ecology, environmental science and economics. It was first put forward by foreign scholars in the process of ecosystem service function and value research. In the 1960s, John Krutila put forward the concept of natural resource value, which laid a foundation for the future study of the value of ecosystem services. In 1970, SCEP first proposed the concept of ecosystem service function, and pointed out the specific environmental service function of ecosystem (Pearce and Turner, 1989). Until 1990, ecological compensation was recognized by most of the scholars, is the destruction of ecosystems to repair or off-site reconstruction to compensate for ecological losses practices (Cuperas, 1996). In the late 1990s, the notion of ecological compensation was introduced into river basin management and was often replaced by "payment for river basin ecosystem services" (PWES) (Zbinden and Lee, 2005). The ecological compensation of river basin means that the beneficiary (polluter) of river basin compensates the protection subject (victim), including compensation, compensation or policy compensation. It takes the resource of a river basin as the carrier to solve the compensation problem caused by the economic profit and loss change in different areas of the river basin. It coordinates the upstream and downstream stakeholders in the basin because of the practical economic imbalance of the interregional interest relationship. Through direct payment of ecology compensation costs behavior, to achieve ecological and environmental protection and the distribution of benefits fairness and justice (Qian and Wang, 2005). In the broad sense, the ecological compensation of the river basin also includes the compensation and policy concessions of the people to the funds, goods and technology in the ecological protection area of the river basin, which are engaged in the ecological protection and construction and lose the development opportunity (Cuperas, 1996).

2.2 River basin ecological compensation

In the ecological compensation, the ecological environment as a public goods, its service externalities and information asymmetry and other characteristics of the efficient allocation of resources adversely affected. Therefore, the government control becomes the first choice of the river basin environmental protection, through the development of a series of systems, policies and regulations, supervision of lower levels of intergovernmental implementation of the coordination of the interests of the various participants in the relationship. In addition to financial, physical and technical compensation, there are policy compensation and project compensation in the form of subsidies for soil and water conservation in the upper reaches of the river basin, which are mainly used in the form of compensation for fiscal transfer payments. However, due to the financial transfer payment "transfusion type" compensation is difficult to achieve environmental protection and economic development of the benign interaction, so the market transaction as a basin ecological compensation model is increasing. River basin market transactions refer to the price and purchase of services by contributors and beneficiaries of ecosystem services in cases where the government directs and supervises trading activities (Wang and Hou, 2013). From the perspective of the future development trend of ecological compensation, foreign countries are gradually commercializing well-defined river basin environmental services, mainly for the ownership transactions and contract signing, environmental service products including water quality and water regulation, water pollution control, groundwater regulation and soil and water loss prevention (Zhao and Hu, 2007).

2.3 Basin ecological compensation calculation

Compensation standard calculation is the key to determine the amount of ecological compensation, but also the key to establish an effective ecological compensation mechanism for the basin, which is directly related to the scientific nature and effect of ecological compensation. The essence of the ecological compensation calculation is that the compensation value can not only reasonably reflect the value, cost and benefit of the ecosystem service function, but also be accepted by the upstream and downstream stakeholders, so as to correct the economic relationship of the stakeholders and purpose of river basin ecological environment. At present, the calculation method of ecological compensation standard can be divided into three kinds: (1) the total ecosystem cost (Cai et al., 2008), (2) the value of river basin ecosystem services (Li et al., 2010), and (3) the maximum willingness to pay or the minimum compensation willingness to determine the amount (Li Guangdong et al., 2011; Zhang et al., 2011; 2007). The compensation standard is calculated from the aspects of natural compensation, economic value ecological compensation and social ecological compensation respectively (Jin et al., 2014).

In the aspect of cost accounting, the direct costs of ecological protection investment in the basin are mainly used in direct market pricing, static accounting and dynamic accounting, and these two methods are often used in combination (Duan et al., 2010). It is difficult to determine the opportunity cost. The accounting method is also controversial. At this stage, the widespread use of field surveys and indirect methods such as computing (Hu et al., 2008). In comparison, the indirect calculation method is more applied and the economic loss caused by the ecological environment protection is calculated by comparing the economic differences between the two regions. In terms of benefit accounting, the eco-environmental benefits of the river basin can be reflected by calculating the value of ecosystem service function, which makes the ecosystem service function "monetized" (Ma and Lin, 2009; Wang and Lin, 2008). Daily & Costanza pushes the research of ecosystem service value accounting to the forefront of resource and environmental economics, and the research progress on ecosystem service function is the most interesting. Daily elaborated on the concept of ecosystem services, research history and assessment of content and methods of topics such as research (Daily, 1997； Costanza et al., 1997). Costanza and other scholars have summarized the international valuation of ecosystem services based on the study, the global biosphere ecosystem services are divided into 17 categories and all the functional values of biological communities were estimated (Costanza et al., 1997). These results have a profound impact on the study of ecosystem service value in China. Based on the evaluation model of ecosystem service value proposed by Costanza et al. (1997) Xie Gaodi and many other ecological experts have been consulted in the form of questionnaires, and finally obtained the "China Ecosystem Service Value Equivalence Factor Table". In this paper, taking Tibet Mangcuo Lake as an example, the total economic value of the service function of the river basin system can be directly calculated through the ecosystem area and service function unit price (Xiao et al., 2003). In addition, the forest resources ecological assets can be classified by GIS technology and the value of forest ecosystem services can be estimated according to the value coefficient (Xie Haodi et al., 2010). In terms of willingness to pay, contingent valuation method (CVM) and choice experiment (CE) are commonly used to account for resource and environmental values. CVM is a typical method of evaluating the value of preference statements (Zheng et al., 2010; Li et al., 2011; Jie et al., 2011; Walsh, 1997; Xu et al., 2012) first proposed by Davis in 1963. The validity of this method has been unanimously recognized by scholars at home and abroad (Zhao and Yang, 2004; Zhang et al., 2011). Different from CVM, choice experiment (CE) not only widens the scope of practice, but also overcomes some shortcomings in CVM. The choice experiment is based on individual behavior and selection model and indirectly calculates non-market products of the monetary value of (Fan and Zhao, 2013; Moran et al., 2007)

2.4 River basin ecological compensation mechanism

The scientific and rational establishment of the ecological compensation mechanism in the river basin can effectively solve the contradiction between the upstream and downstream stakeholders on the ecological environment protection and economic development, so as to achieve "win-win" in all regions and achieve the purpose of coordinated development of interregional river basin (Zhang et al., 2012; Xu et al., 2012). The essence of which is to realize the internalization of external resources and increase the value of ecological capital in the basin by some means (Wang and Hou, 2013; Liu et al., 2010). Therefore, the river basin ecological compensation should adhere to the principle of "benefit sharing and responsibility sharing" in the middle and lower reaches of the river basin, strengthen the compensation among different regions in the basin, and gradually form the ecological environment protectionists to provide ecological products downstream environmental beneficiaries to buy and pay the corresponding costs eco-environmental protection to obtain compensation funds to stimulate its ecological environment to enhance the positive "interactive mechanism" (Li and Gai, 2011).

2.5 The measurement of efficiency of compensation mechanism of river basin eco- environment

At present, there are few studies on the efficiency of ecological compensation in China. The analysis of the efficiency of ecological compensation in the river basins is mainly focused on four key issues: scientific ecological compensation baselines, ecological compensation spatial positioning, real opportunity cost estimation and transaction cost reduction (Wunder, 2005; 2008; Ferraro and Pattanayak, 2006; Pagiola, 2005; 2008; Engel et al., 2008; Li et al., 2011). In the future, the study on ecological compensation should pay attention to the comparison between the ecological service function and private profit and loss of the river basin, and consider the influence factors of the expected ecological compensation cost and the ecological service cost, and grasp the ecological compensation to improve the ecological compensation dynamic baseline assessment of efficiency.

3 CURRENT SITUATION AND EXISTING PROBLEMS OF ECOLOGICAL COMPENSATION MECHANISM IN CHINESE RIVER BASIN

3.1 The development of ecological compensation mechanism in Chinese River Basin

Since the 1990s, China has carried out ecological compensation practice in the fields of forest and mineral resources, and has accumulated some experience in ecological compensation system design. However, due to the lack of laws and regulations, the lack of management system and the imperfect property rights system, China's ecological compensation system needs to be further improved. Especially the river basin ecological compensation mechanism as water flow and become more complex. China's ecological compensation mechanism is first developed in forestry ecological environment management and then extended to the mineral resources development, wetlands, oceans, forests, grasslands, key ecological functional areas, agriculture, drinking water source protection, water resources and river basins and other fields (Figure 1).

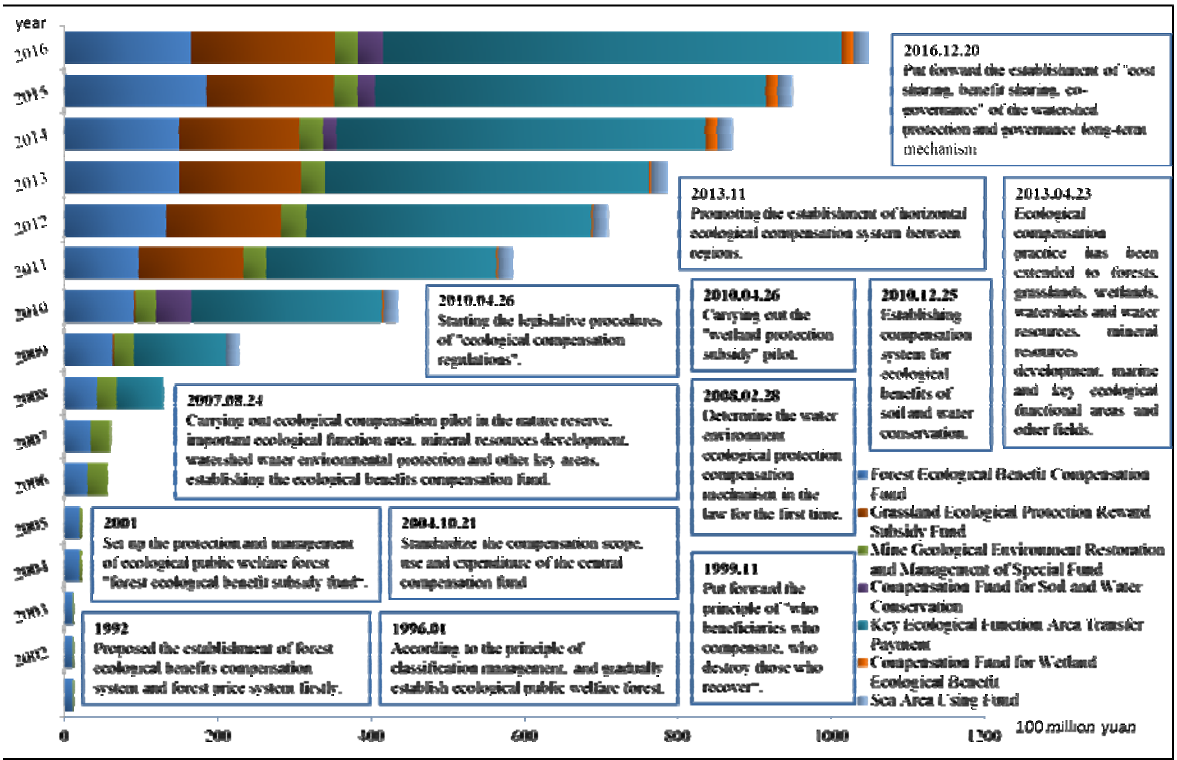

Figure 1. Development process of Chinese River Basin ecological compensation mechanism.

3.2 Practice of ecological compensation mechanism in Chinese River Basin

The main way of ecological compensation is to use the market as the main form of ecological compensation operation (referred to as market compensation) and the government as the main form of ecological compensation operation (referred to as government compensation). China's current ecological services compensation is still in the initial stage of exploration, the basin ecological service compensation mechanism is still the main government to buy or participate in the market mechanism can only be in the condition of small and medium-sized watershed supplement and auxiliary role. At present, the practice of ecological compensation in the province is more and the ecological compensation of the river basin is less (Table 1).

4 ESTABLISHMENT OF INDICATOR SYSTEM FOR ECOLOGICAL EFFICIENCY EVALUATION OF RIVER BASIN

The ecological compensation of the river basin is an interest-driven mechanism, incentive mechanism and coordination mechanism (Rao et al., 2014), which is of great significance to the economic development and environmental protection of the river basin as a water resources protection and ecological environment construction behavior. The index system of ecological compensation efficiency of river basin can be regarded as an information system, which provides comprehensive and objective system information for the development of river basin ecological compensation in a concise way. Through this information, we can understand the basic parameters of the ecological compensation efficiency of the river basin so as to timely discover the problems and put forward the corresponding control measures and measures to promote the ecological compensation of the river basin towards healthy and benign state.

4.1 Index system screening method

Firstly, we take the frequency analysis method from the domestic and foreign environmental engineering evaluation indicators, ecological compensation efficiency measure and other relevant research literature frequency statistics, screening the use of high frequency indicators. Secondly, using fish bone analysis (Figure 2), this paper analyzes the factors influencing the efficiency of ecological compensation in the basin from the social, economic, ecological, cultural and political aspects and selects the indicators of importance and pertinence. On this basis, combined with the characteristics of river basin ecological compensation, the AHP method is adopted to comprehensively consider the scientific nature of the measure, the availability of data and reflect the comprehensiveness of the problem, and construct the index of ecological compensation efficiency system. The first level target layer is denoted by A, and the second dimension is represented by B, which includes social efficiency B1, economic efficiency B2, eco efficiency B3, cultural efficiency B4, and political efficiency B5. The third level target layer is the branch of the dimension layer, denoted by C.

Table 1. Practice of ecological compensation in China.

River Basin Ecological Compensation	Content	Sources of Funds	Practice
Government Compensation	Financial transfer payment	Central finance vertical transfer payment	Three North and Yangtze River Basin Shelter Forest System Construction Project Returning farmland to forest (grass) works
		Local finance vertical transfer payment	Zhejiang Province to arrange financial transfer to pay funds 1 billion yuan / year on the province's eight major waterways in 45 counties and cities in the assessment of ecological function protection and environmental quality improvement and other indicators on the basis of classification of sub-file to calculate the allocation of ecological compensation funds Jiangxi Province arranged 130 million yuan / year on the "five rivers and one lake" (Ganjiang River, Fu River, Xinjiang River, Rao River, Xiuhe and Poyang Lake) and Dongjiang source of ecological protection Fujian Province to take downstream compensation upstream, provincial financial support, the upstream supporting methods to raise funds, specifically for the Jiulong River, Minjiang, Jinjiang ecological environment remediation
		Horizontal transfer payment	Yaoxian County of Shaanxi Province compensates the forestry sector of the upstream water source area by 10% of the annual water resource tax Anhui and Zhejiang provinces to water quality "on gambling", set 500 million yuan per year compensation fund (central government subsidies 300 million yuan, the two provinces each invested 100 million yuan), to carry out inter-provincial horizontal ecological compensation
	Ecological compensation fund	Donations from international environmental NGOs, poverty alleviation funds, and transfers from the state finance	Deqing County, Zhejiang Province from the land transfer fees, water resources and other funds raised in the proportion of part of the establishment of ecological compensation fund for the ecological protection of the financial incentives
	Policy compensation		Fiscal policies are formulated for environmental protection and ecological construction of water source areas
	Off - site development		The "industrial enclave" of the Jinhua River in Zhejiang Province compensates the loss of lost industrial projects in the upper reaches due to the implementation of protection
Market Compensation	Water Rights Transactions	Water right to permanent use rights	Zhejiang Province, Jinjiang River upstream and downstream of Dongyang City, Yiwu City, water rights transactions, access to the upper reaches of Yiwu City, 50 million cubic meters of water Hengjin permanent right to use, and the cost of compensation to the upper reaches of Dongyang City Ningxia Hui Autonomous Region, Inner Mongolia Autonomous Region upstream irrigation area through water-saving transformation, the excess water sold to the downstream hydropower station
	Water warrants	Water market sale proceeds	Gansu Heihe River Basin according to each household contract area and the number of people and water distribution of water rights, "water warrants" can be sold through the water market, determined by the market price
	Upstream and downstream eco-environmental service transactions	Payment of compensation	Lijiang City, Lijiang City, Yunnan Province, "change the lake for the sea", in order to compensate for the impact caused by the dam to pay the upper reaches of the compensation
	Eco - labeling	Water Resources Environment Consumer Indirect Payment	Nongfushangquan company in a bottle of water out of a penny donated to the water source enterprises, water sources to compensate the people to protect the water source suffered economic losses

4.2 Influencing factors of ecological compensation efficiency of river basin

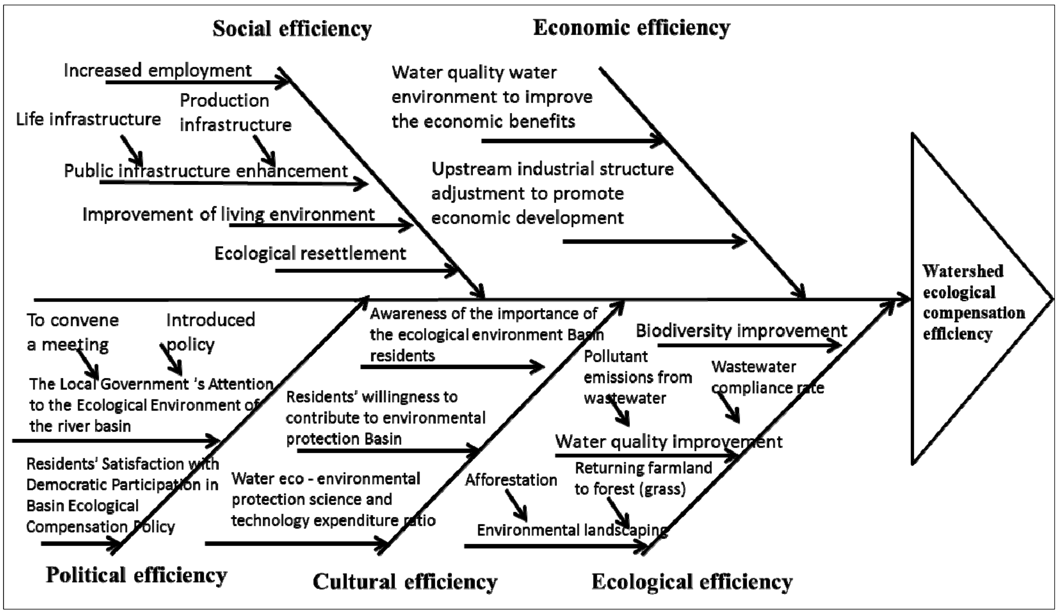

Figure 2. Fish bone analysis for influencing factors of ecological compensation efficiency of river basin.

4.3 Establish a judgment matrix

The evaluation subject needs to carry out a series of two pairs of comparison to determine the relative importance of the index and the judgment matrix should follow the relative importance of the value of the rules. First, according to the importance of the value of the rules, the reference to the views of water ecological experts, the water quality of the water quality, the judgment matrix of dimension layer and target layer is given respectively. The relative importance value rule and the n-order judgment matrix are as follows (Table 2):

Table 2. Value rule for relative importance.

Serial number	Score	Value rule
1	1	Factor i and factor j are equally important relative to an attribute
2	3	Factor i is slightly important with factor j
3	5	Factor i is more important than factor j
4	7	Factor i is significantly more important than factor j
5	9	Factor i is absolutely important than factor j
6	2、4、6、8	Between the two adjacent factors to determine the middle
7	$1/x_{ij}$	Factor j is more important than factor i

$$X = x_{ij} = \begin{matrix} \frac{a_1}{a_1} & \frac{a_1}{a_2} & \cdots & \frac{a_1}{a_n} \\ \frac{a_2}{a_1} & \frac{a_2}{a_2} & \cdots & \frac{a_2}{a_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{a_n}{a_1} & \frac{a_n}{a_2} & \cdots & \frac{a_n}{a_n} \end{matrix}$$

where $\frac{a_i}{a_j}$ indicates the importance of the index a_i relative to the index a_j, given by expert judgment.

4.4 Normalization and judgment matrix weights calculation

We put the above dimensions of the expression, through the normalized, into a dimensionless expression. The normalized formula is $x_{ij}' = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$ where x_{ij} is the data matrix to be normalized, and x_{ij}' is the normalized data, which is between 0 and 1. According to the formula, we first calculate the product of each row of the judgment matrix, $M_i = \prod^n x_{ij}'$ （$i, j = 1,2, \cdots, n$） , then M_i is processed $\overline{W_i} = \sqrt[n]{M_i}$, we obtain the eigenvector $W = \overline{W_i}, \overline{W_2}, \cdots, \overline{W_n}^T$. According to the above weight calculation method, the weights of each index in the comprehensive efficiency model of river basin ecological compensation are obtained and the weight obtained is shown in the following table.

Table 3. Index system for ecological compensation efficiency measurement of basin water resource with weight distribution.

Comprehensive Efficiency of Ecological Compensation of Water Resources in River Basins A				
SOCIAL EFFICIENCY B1(0.442)	**ECONOMIC EFFICIENCY B2(0.221)**	**ECO - EFFICIENCY B3(0.1727)**	**CULTURAL EFFICIENCY B4(0.0822)**	**CULTURAL EFFICIENCY B5(0.0822)**
C11 New Job from River Basin Ecological Compensation Policy (0.157)	**C21** Reduced Water Environment Governance Investment (0.014)	**C31** Industrial Wastewater Discharge (0.017)	**C41** Sensitivity of Residents to Environmental Changes in the River Basin (0.028)	**C51** Development of Ecological Compensation for River Basin Related Policies Frequency of Meeting (0.026)
C12 Tap Water Proportion of The Village(0.015)	**C22** Contribution Rate of Industrial Waste Water (0.014)	**C32** Industrial Wastewater Discharge Compliance Rate(0.014)	**C42** Willingness of Contribution to Ecological Environment Protection of the residents in the River Basin (0.026)	**C52** Basin Ecological Compensation Related Regulations Policy Introduction Frequency (0.030)
C13 Energy Consumption per Capita (0.038)	**C23** Growth Rate of Added Value of Agriculture, Forestry, Animal husbandry and Fishery (0.033)	**C33** COD Emissions from Industrial Wastewater (0.011)	**C43** Expenditure Ratio of Water Eco-environmental Protection Science and Technology (0.0282)	**C53** Residents' Satisfaction with Democratic Participation in Basin Ecological Compensation Policy(0.0262)
C14 Domestic Water Consumption (0.045)	**C24** Growth Rate of Tertiary Industry Output Value (0.013)	**C34** Ammonia Nitrogen Emissions from Industrial Wastewater (0.0847)		
C15 Percentage of Garbage Disposal Centralized Villages (0.025)	**C25** Growth Rate of Forestry Output (0.009)	**C35** New Comprehensive Management of Soil Erosion Area (0.01)		
C16 Effective Irrigation Area (0.077)	**C26** Special Income Ratio (0.006)	**C36** Urban Public and Ecological Water Consumption (0.009)		
C17 Ecological Resettlement Acceptance Rate(0.085)	**C27** Agricultural Water Use Ratio (0.043)	**C37** Biodiversity Improvement (0.01)		
	C28 Proportion of Industrial Water (0.053)	**C38** Returning Farmland to Forest (grass) Area (0.007)		
	C29 Energy Consumption per Unit of GDP (0.036)	**C39** Afforestation Area (0.01)		

4.5 Verify the consistency of the judgment matrix

Through the establishment of judgment matrix and normalization process, the weights of each index in the comprehensive efficiency model of water resources ecological compensation are obtained. Finally, the author tests the consistency of the comparison matrix based on the contrast matrix formula. The specific test steps are as follows:

(1) Calculate the consistency index$CI =$ （$\lambda_{max} - n$） $/n - 1$, where $\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)_i}{w_i}$, CI is Compare the maximum eigenvalue of the discriminant matrix.

(2) Calculate the consistency ratio CR, $CR = CI/RI$， , where RI is the empirical statistic, determined by the dimension of the discriminant matrix.

(3) When $CR < 0.1$, it is considered that the consistency of the discriminant matrix is acceptable, otherwise it is considered that the inconsistency is too serious and the adjustment matrix needs to be adjusted appropriately.

According to the consistency judgment method shown in the above, the consistency index of each level index can be obtained as shown in the Table 4:

Table 4. Consistency index.

	$\lambda_{\max}$	CI	RI	CR	Judgment criteria	Test result
A-B	5.0247	0.0062	1.12	0.0055	0.1	Consistent
B1-C	11.4878	0.0488	1.53	0.0319	0.1	Consistent
B2-C	10.0792	0.1349	1.45	0.0930	0.1	Consistent
B3-C	20.0667	0.1216	1.6133	0.0754	0.1	Consistent
B4-C	8.1478	0.0211	1.41	0.015	0.1	Consistent
B5-C	4.2165	0.0722	0.9	0.0802	0.1	Consistent

5 CONCLUSION AND PROSEPECT

The ecological compensation of water resources utilization in the basin is still in its infancy stage in China, but it is a realistic subject with a wide range of implications. Although in recent years, our local governments have carried out practical exploration on the ecological compensation of water resources utilization in the river basins, but there is no uniform ecological compensation system for guiding the river basins. Most of the local governments have no legal support for the corresponding ecological compensation policies. There is no uniform compensation standard calculation method, compensation and supporting measures are not in place, which seriously restricts the ecological compensation work in China. It is necessary to establish a unified ecological compensation system for interests, introduce legislation on ecological compensation of river basin water resources, explore a unified compensation standard calculation method, improve the ecological compensation system of water resources, water resources ecological compensation contradiction dispute settlement system and other supporting system measures to protect sustainable development of river basin water resources. With the continuous improvement of water resources ecological compensation system in China, it is necessary to improve the index system of ecological compensation efficiency in order to more accurately measure the ecological compensation efficiency of river basin water resources. In the implementation of the new system will encounter different problems, need to analyze and solve, so that the system continues to improve in order to promote sustained and coordinated development of river basin health.

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RIVERBANK FILTRATION (RBF) INDEX AND EFFECTIVENESS OF RBF AT WEST MALAYSIA

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ABSTRACT

Drinking water supply in Malaysia is based on surface water abstraction (98%) and groundwater (2%). As Malaysia is currently facing problems with climate change and the pollution of surface water by industrial, agricultural and municipal inflows, riverbank filtration (RBF) would offer in situ water treatment process and a low cost alternative for pre-treatment of raw water for potable use. The objective of this paper is to evaluate the potential of selected riverbank filtration in Langat River, Linggi River and Muda River, Malaysia based on drilling at potential sites and monitoring of both water level and water quality parameters. Analysis of the feasibility of RBF for three sites based on hydrogeology have been also evaluated. The evaluation of three sites receiving a bank filtration share of more than 80 % and producing drinking water has proven the feasibility of riverbank filtration in Malaysia. Main issues for the feasibility of RBF in Malaysia are found to be the hydraulic connection between surface waters and the adjacent aquifer and the surface water and groundwater quality. The Malaysia Rivers has hydraulic connection with a Quaternary aquifer that is comprised of coarse sandy riverine sediments. The coarse sandy riverbed and coarse aquifer materials have a sufficient hydraulic conductivity for RBF. As an interesting aspect, the siting of the pumping well near to the river is also considered. It is recommended that, wells are constructed at short distances from the river bank, to get a high share of bank filtrate and reduced the iron (Fe) and manganese (Mn) from the borehole.

Keywords: RBF index; bank filtration share; riverbank filtration; water quality of bank filtration; enhancement of river.

1 INTRODUCTION

El Nino phenomenon will affect water resources in Malaysia. Malaysia is blessed with stable water quantity and quality and easy access of conjunctive use surfacewater and groundwater management. Thus, riverbank filtration (RBF) is suitable to be adopted in this country and is an important of groundwater exploitation. The design and concept of RBF was common in Europe since 1870 (Schubert, 2002). In Switzerland, France, Finland, Hungary, Slovakia, Germany and Holland, the proportion of total drinking water supplied by RBF has reached 80%, 50%, 48%, 45%, 50%, 16% and 5% respectively (Tufenkji et al., 2002; Hiscock and Grischek, 2002). The conjunctive use of surfacewater and groundwater resources can be used through RBF, which stimulate and increase the recharge of river water to the aquifer (Shamsuddin et al., 2014). RBF is the infiltration of river water into a well through the riverbed and underlying aquifer material such as sand. This is a natural filtration process in which physic-chemical and biological processes play a role in improving the quality of percolating water. After a certain zone of mixing and reducing, the infiltrated water is at its cleanest, almost all river contaminants are removed. Wells are installed in this zone to pump the water to be used for drinking. The purity of this water and its suitability for drinking is outstanding, even in examples where there is an event that introduces a shock load of contaminants in to the river. Due to the geologic media's ability to remove the contaminants and travel time of water abstracted for natural filtration, the impact of such an event is minimal. In Malaysia, the National Hydraulic Research Institute of Malaysia (NAHRIM) evaluated the feasibility of developing the RBF system along the major rivers to mitigate water shortage problem of water supply for domestic and industrial consumption. One of the main tasks in the RBF development project is the feasibility of site to develop the RBF system. The success of RBF depends on favorable hydrogeological conditions near the river. Riverbank filtration relies on the ability of a well to induce recharge from a nearby surfacewater source, with the degree of hydraulic connection between surfacewater and groundwater is often the factor that limits wellfield capacity. However, it is site specific and requires extensive site investigations and pilot studies to assess its feasibility based on local conditions. In Malaysia guidelines or index system of RBF was not available to evaluate the suitability of RBF and the transfer of this sustainable and multiple-contaminant removal technology. Though very appropriate for both developed and developing countries, RBF has not been utilized (fully) in developing countries due to lack of knowledge and tools/methods for design of such systems. Factors affecting performance of RBF System such as site specific, conditions source (river, lake), geology and soils, geohydrology ‹alluvial, unconfined aquifer, aquifer depth (depth to water table), permeability (hydraulic conductivity), travel distance, well placement and spacing between wells, travel (residence), time well placement and operation (pumping Rate) and permeability (conductivity) is more important factor to develop the index system. Design components for RBF system including number of wells (production capacity per well), spacing between the wells, distance of the wells from the riverbank, share (%) of river water and native groundwater. Water quality obtained from the RBF system, and post-treatment requirements will be considered in the index system of RBF. In this research, the downstream river basin of the Langat River, Linggi River and Muda River was set as the study area and the potential RBF index suitable area for RBF was evaluated. Based on the analysis of natural geography and hydrogeological conditions, an index system was established to evaluate the suitability of RBF along the main of the river in the study area. The aim of this research is to find potential suitable areas for future water development plans and conduct further detailed investigation of RBF systems. The specific goal of RBF is mainly to provide sufficient water resources with good water quality. A multi-criteria RBF evaluation index system was established based on water quantity, water quality, the development and utilization conditions of groundwater resources and the interaction intensity between surface water and groundwater. The index weight and detailed score criteria were all based on specialist marking methods, which is more effective for a specific site but may not be applicable to other areas.

2 STUDY SITE

RBF in West Malaysia aims to achieve the strategic goals of improving drinking water production including an improved availability and increase sustainability of drinking water supply at high quality, at low cost and with a limited generation of waste or contaminant product. This RBF pilot study site offers important advantages as the researchers can evaluate the RBF index of RBF technique for River in Malaysia. For this downstream river basin of the Langat River, Linggi River and Muda River, and was calculated the feasibility RBF index based on the parameters affecting yield in RBF systems. Three study sites for this study were chosen based on the following criteria:

2.1 Bank Infiltration systems

2.1.1 Langat River

The Langat riverbank corridor area at the Jenderam Hilir located approximately some 5 km south of Putrajaya was chosen and has been identified as potential site to do the feasibility study of using RBF system. It extends between latitude 2^0 53' 28.56" N - 2^0 53' 39.75" N and longitude 101^0 42' 03.78" E – 101^0 44' 14.58" E, covering an area of 10 km2 radius (Figure 1.1). The aquifer system in the study area consists of alluvial deposits of sand, silt and gravel which form shallow aquifer. The unsaturated zone sits on the aquifer consists of clay. The thickness of this clay layer is about 1-3 m. The aquifer is mostly of fine to coarse grained sand with mixture of gravel. The thickness of aquifer layer ranging from 5-20 m. It can be locally heterogeneous due to the presence of beds of fine to coarse-grained sand. Based on drilling information, gravelly sand or sandy gravel aquifer layer are overlain by layer of clay, while some areas are overlain by a layer of low permeability fine sand or silt which make the aquifer unconfined and semiconfined depending on locations. Bedrock in the study area is located at depths of 20 m. Due to the presence of sandy gravel which has high porosity and transmissivity, and connection to the river, during high river flow, water from the river recharged the aquifer. Meanwhile during the river low flow, groundwater is discharged into the river. Rechargeable between river and groundwater through riverbed layer can be slow or fast depending to the thickness of hyporheic zone layer.

The average mean monthly flow at the study area is about 32.15 m^3/s. The 80% dependable flow for Langat River is 19 m^3/s. The average low flow is 4.76 m^3/s for year 1978 – 2013. The riverbed permeability is 0.4 m /day. The result of the river survey has shown the cross sections single thread channel with bank full width ranging from 22.75 m to 50.20 m that represents a medium size river. Two new test wells i.e. TW1 and TW2 with outer diameter of 250 mm, at a depth of 14.50 and 15.42 m respectively were constructed to determine the hydraulic parameters of the wells and aquifer. The pumping test at TW2 was started at a rate of 12.90 m^3/hour with static water level of 3.24 m below top of casing (TOC). The flow rate was constant throughout the test at 64.50 m^3/hour. The total drawdown at the end of the one day pumping test was 3.16 m. Recovery test in TW2 after step-drawdown test shows that the water level recovered back to 3.53 m after 7 hour pump stop with efficiency of 90.82%. The static water level was 3.50 m and the final water level was 7.03 m below ground level. The T and K values for TW2 were 42.16 m^2/hour and 2.72 m/hour. According to this aquifer test, the range of travel time from river water to recharge the aquifer is averaged at 3-4 days. The travel time was estimated by dividing K in m/day with the aquifer thickness. The test well TW2 has successfully shown that well-constructed along the river banks is capable of yielding significant volume of water with very much better quality. Recovery in TW2 shows that the water recovered from final water level (7.03 m bgl) to 4.2 m bgl within 1 hour (80%), then slowly recovered after that. For TW1, a step-drawdown test (three steps), a 72 hours constant discharge test. The pumping test at TW1 was started at a rate of 6.53 m^3/hour with static water level of 6.47 m below top of casing (TOC). The flow rate was constant throughout the test at 10.10 m^3/hour. The final water level was 7.44 m. The total drawdown at the end of the one day pumping test was 0.97 m. The recovery test in TW1 after step-drawdown test shows that the water level recovered back to 6.66 m after 1hour pump stop with efficiency of 80.41%. The constant discharge test was carried out with a pumping rate of 10.10 m^3/hr. The static water level was 6.09 m and the final water level was 7.45 m below ground level. The T and K values for TW1 were 9.24 m^2/hr and 0.63 m/hour. The drawdown of TW1 was very low, this shows that the well is capable of producing much higher amount of water but due to limitation of effective aquifer layer and pressure from thickness clay layer on top of aquifer, can cause slow recharge from the river. According to this aquifer test, the range of travel time from river water to recharge the aquifer is averaged at 1-4 days. The travel time was estimated by dividing K in m/day with the aquifer thickness.

2.1.2 Linggi River

The location of the RBF study is located at Water Treatment Plant Linggi River, Negeri Sembilan. It is located at the riverbanks of the Linggi River. Linggi River Water Treatment Plant supplies 60% and 100% of the water requirements for Seremban and Port Dickson, respectively (Figure 1). A total of 35 exploration wells of 50 mm diameter were constructed as a preliminary assessment on the potential of the ground water in the study area. Based on information obtained from exploration wells, the next six test wells were constructed in which five wells constructed in layers of alluvium and one well in hard rock. Test wells in the alluvium has a depth ranging from 6 m to 13 m with a diameter of 254 mm and the test well in hard rock with a depth of 36 m with a diameter of 152 mm. The discharge from test well in hard rock was estimated less than 5 m^3/hour during the drilling. However the test wells in the alluvial water discharges ranging from 28 m^3/hr to 65 m^3/hour. Generally, the drilling of the 100 mm diameter monitoring borehole encountered yellowish brown soft clay with some decaying wood fragments from the surface to a depth of 2.0 m, followed by dark grey medium grained sand up to a depth of 3.50 m. This is followed by dark grey fine grained sand with slightly clay up to 5.50 m, followed by dark grey medium to coarse sand and some dark grey silty to fine grained sand up to 7.20 m, followed by schist bedrock. A total of 35 units of 50 mm diameter shallow alluvium piezometers and two (2) units of 150 mm diameter shallow alluvium test wells were constructed along Linggi River riverbank. The Step Drawdown Test that was carried out on the exploration tubewell SL-TW 1 consists of 5 discharging steps, each step for duration of 90 minutes. The 4 discharging steps that were carried out were 5.5 m^3/hour, 6.5 m^3/hour, 7.5 m^3/hour and 8.5 m^3/hour. The initial static water level was at 1.30 m below ground level, and the final water level was at 2.83 m below ground level, with a total drawdown of 0.52 m. The Constant Discharge test was carried out at a rate of 7.96 m^3/hour for the exploration tubewell SL-TW1. This is the maximum capacity of the submersible pump that was used for the pumping test. The initial static water during the Constant Discharge Test was 1.1 m below ground level and the final water level after pumping non-stop for 72 hours was 2.37 m, with a total drawdown of 1.27m. The transmissivity value is 1.37 m^2/hour. The procedure for Recovery Test is for the water level in the pumped tubewell to achieve 80% recovery from its initial static water level. The Recovery Test was carried out for a total of 4.5 hours. The initial residual drawdown was 2.37 m, and the residual drawdown after 4.5 hours was 0.3 m, with a recovery of 76.38%. The transmissivity value for the Recovery Test is 18.21 m^2/hour. Constant Discharge Test was performed on the test wells SL-TW2 to determine aquifer characteristics. During the pumping tests, drawdowns of the groundwater level were also measured at the nearby monitoring wells (SL-MW15, SL-MW14, SL-MW13, SL-MW12, SL-MW11 and JL13). After the constant pumping at a rate of 17.1 m^3/hour for 72 hours, the final drawdown is 7.24 m with a total drawdown of 5.65 m. The total drawdown at the monitoring wells ranged from 0.69 m to 1.05 m. Based on this analysis, the hydraulic conductivity of the test wells SL-TW2 is 17.1 m/day, while for monitoring wells ranged between 54.1 to 63.1 m/day. The average of the hydraulic conductivity is 53.1 m/day. Transmissivity for the test well is 102 m^2/day, while for monitoring wells ranged between 325 to 379 m^2/day. The average value of the transmissivity is 319m^2/day. The Recovery Test resumed immediately after the Constant Discharge Test was completed. The Recovery Test was carried out for a total of 120 minutes after the pump was shut down. For a period of 120 minutes after the pump is shut down, the remaining drawdown of the test well SL-TW2 is 0.2 m, while for monitoring wells ranged from 0.15 to 0.64 m. Based on this analysis, it was found that the hydraulic conductivity of the test well SL-TW2 is 16.7 m/day, while for monitoring wells ranged between 38.8 to 51.1 m/day. The average hydraulic conductivity value is 43.0 m/day. While the transmissivity value for the test well is 100 m^2/day, and for monitoring wells ranged between 233 to 306 m^2/day. The average transmissivity value is 258 m^2/day. Based on Kozeny-Carman equation, the hydraulic conductivity is between 3.6 to 174.6 m/day with an average of 48.5m/day. Hydraulic conductivity values based on the Hazen are between 6.79 to 202.7 m/day with an average of 61.4 m/day. The values obtained are compatible with the results of grain size analysis carried out which showed that medium to coarse grained sand is the dominant size in the study area. The transmissivity, T values obtained from the Constant Test and Recovery Test ranged between 100 to 379 m^2/day, with an average of 257 m^2/day. Storage coefficient, S is obtained from discharge test equipment for pumping the test wells. The results of the analysis conducted found that storage coefficients ranged between 4.17x10-4 and 2.6x10-1 with an average of 3.93x10-2.

2.1.3 Muda River

The study area is located in the northwest state of Kedah and Pulau Pinang within the Muda River Basin, Peninsula Malaysia, and extends between RSO longitudes $100^0$29’0” to $100^0$33’30” Easting and latitudes $5^0$32’30” to $5^0$35’30” Northing and covers an area of 35 km2 (Figure 1). The nearest town to the study area is Sungai Petani (Kedah) and Kepala Batas (Pulau Pinang). The Muda River has been developed as one of the most important water resources for agriculture and water supply for Kedah and Pulau Pinang. The three major tributaries of Muda River system are Ketil River, Sedim River and Chepir River. This location near to the residential and crops area. The Muda River is the longest river in the state of Kedah with its upstream flow coming from the northern mountainous area of the state. The river which has length of 180 km, flows towards the southern area of the state and has a catchment area 4210 km^2. Downstream, the river charges its course towards the west coast after passing the confluence of the mainstream and its larges tributary which is the Ketil River. The annual rainfall in the study area is about 2000-3000 mm. Both Kedah and Pulau Pinang have the rights to use the water from the Muda River. The Quaternary stratigraphy of the study area is divided into Beruas Formation and Gula Formation. The uppermost layer is the Beruas Formation consisting of Holocene terrestrial sediments of brownish color. Underlying the Beruas Formation is the Gula Formation. It is comprised of clay, silt, and sand with shells. The presence of the Gula Formation acts as an impermeable layer, thus confining other formations beneath it. This site was chosen for RBF study due to the high water demand in the area and groundwater is seen as one of the source with very high potential to be developed as supplementary source to meet the high public water supply demand. Fifteen monitoring wells and two test wells were constructed at the study site and pumping tests have been carried on these two test wells. The pumping tests indicated that TW1 were able to produce 43.92 m^3/h and TW2 is about 51.609 m^3/h during the duration of 72 hours pumping tests with drawdown 3.22 m and 1.88 m respectively. Water quality analyses were carried out from the Muda River and groundwater. From the study site showed decreased in turbidity, nitrate, aluminium and sulphate in groundwater. The study on the effectiveness of BI method in Muda River Basin, Pulau Pinang and Kedah shown that the water quality from BI is improved rather than river water quality and the quantity of water abstraction is high because depth of aquifer is about 30 m from ground level. The study was carried out to evaluate the hydraulic properties of the aquifer and riverbed and to determine the effectiveness of the BI at Muda River. Grain size analysis was conducted to identify the proportion of clay, silt, sand and gravel for both test well (TW). Based on the results of grain size analysis, the aquifer composed of fine to coarse grained sand with a mixture of gravel and higher moisture content down to the base of the aquifer system. The hydraulic conductivity of riverbed sediment based on grain size analysis is 80 m/day and the width of Muda River is 90 m to 130 m.

3 METHODOLOGY

3.1 Distance of RBF

The distance of RBF from the river to the study area was firstly considered following these two criteria:

(i) The length of riverbank affected by a RBF system increases with the number of the applied wells and is expected to significantly influence yield. The more wells situated along the riverbank, the longer the reach of the river the aquifer gains recharge from runoff flow;

(ii) Hydraulic connection extent between river water and groundwater. The feasibility of RBF is getting worse and may even be impossible with increasing distance from river. In order to get more complete background information on potential RBF sites, a large study area was recommended. According to the runoff quantity, the study range of RBF was divided along the river (Table 1). Where there is a surface water divide in the study range, this natural feature is used as the boundary of the study area.

Table 1.Type of surface runoff and distance of RBF to river.

Type	1	2	3	4	5
Surface runoff (m3/day)	>600	600-250	250-100	100-40	<40
Distance from river (m)	200	180	150	130	100

3.2 Evaluation index system

The aim of this research is to find potential suitable areas for future water development plans and further detailed investigation of RBF systems. The specific goal of RBF is mainly to provide sufficient water resources with good water quality. A multi-criteria RBF evaluation index system was established based on water quantity, water quality, the development and utilization conditions of groundwater resources and the interaction intensity between surface water and groundwater. The index weight and detailed scoring criterion were all based on specialist marking methods, which is more effective for a specific site but may not be applicable to other areas (Table 2).

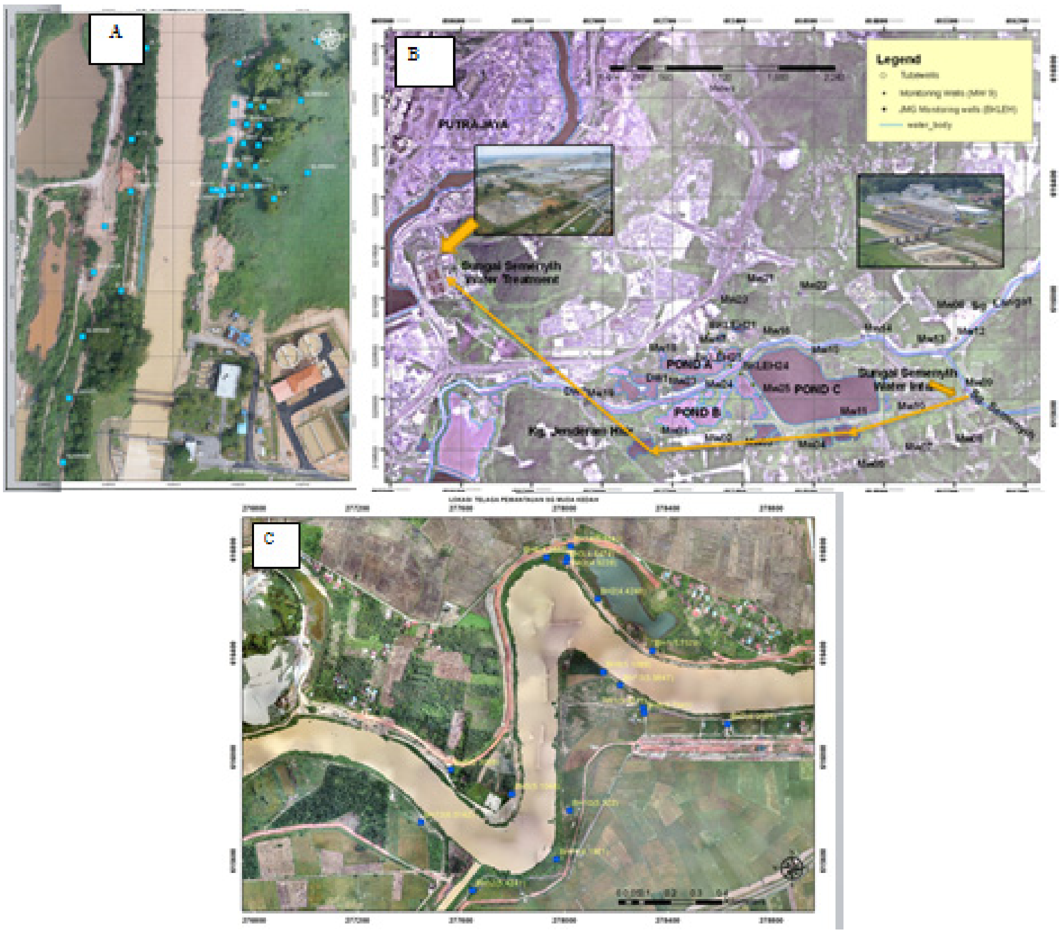

Figure 1. The location of the study area (A) Linggi River, (B) Langat River and (C) Muda River and the test wells and monitoring wells at the study area

Table 2. Evaluation index system and index weight.

Category of evaluation Index		Evaluation Index (X)	Index Weight (W)	
Water quantity	groundwater	Hydraulic conductivity (K)	0.10	0.30
		Aquifer thickness (M)	0.10	
	surfacewater	Runoff in cross section (Q)	0.10	
Water quality	groundwater	Status of groundwater (G)	0.15	0.30
	surfacewater	Status of surface water quality (S)	0.15	
Interaction intensity between surfacewater and groundwater		Groundwater hydraulic gradient (I)	0.10	0.30
		Possible influence zone width of surfacewater under the condition of groundwater exploitation (L)	0.10	
		Permeability of riverbed layer (R)	0.10	
The exploitation condition of groundwater resource		Groundwater Level (D)	0.10	0.10

The main reasons for index weight are explained as follows: (1) The sum of evaluation index weight is equal to 1 by value assignment. The index weight of water quantity, water quality and interaction intensity between surface water and groundwater each accounts for 0.3 of total weight individually, and this allotment reflected the aim and decisive factors of RBF suitability evaluation of the study site. The index weight of development and utilization conditions of groundwater resources only account for 0.1 of total weight, because the factor will influence groundwater development cost and help to confirm the priority, but it is not a decisive factor for RBF suitability evaluation; (2) For the index of water quantity, the groundwater index accounts for 0.20 and surface water index accounts for 0.1, because the water source of RBF waterworks comes from riverside groundwater and surface water via bank filtration. Hydraulic conductivity and aquifer thickness influence the infiltration rate and capacity of surface water to aquifer; (3) For water quality, the index weight of groundwater and surface water are equal to 0.15. The groundwater quality only indicates the current status and treatment effect of RBF. In order to avoid any possible groundwater contamination from surface water, the treatment effect of RBF should not be addressed too much and the surface water quality should not be neglected; (4) The interaction intensity between surface water and groundwater controls the water exchange efficiency. Only those places within the influence zone of surface water, the aquifer prone to receiving sufficient water quantity through RBF, the permeability of riverbed layer controls the real water exchange rate and the groundwater hydraulic gradient partly reflects the real condition of aquifer property; (5) The index weight of groundwater depth accounts for 0.1, because it will only influence the priority order of potential RBF areas.

3.2.1 Water quantity

(1) Hydraulic conductivity (K)

Aquifer hydraulic conductivity (K) reflects lithology and permeability of an aquifer. The index value of hydraulic conductivity is shown in Table 3.

Table 3. Index value of hydraulic conductivity (K).

K (m/d)	>100	100-50	50-20	20-5	5-1	1-0.1	<0.1
Index value	100	90	80	70	60	30	0

(2) Aquifer thickness (M)

A suitable RBF site requires a certain scale of aquifer for adequate water production. The aquifer thickness index value is shown in Table 4.

Table 4. Aquifer thickness (M) index value.

M (m)	>50	30-50	10-30	5-10	3-5	1-3	<1
Index Value	100	90	80	70	60	30	0

3.2.2 Surface runoff (Q)

The larger the annual average surface runoff, the greater the recharge potential of surface water to groundwater, and the greater the potential suitability of the area for RBF. The surface runoff index values are shown in Table 5.

Table 5. Surface runoff index value.

Q (m3/day)	250-100	100-40	40-10	10-5	5-1	1-0.1	<0.1
Index value	100	90	80	70	60	30	0

3.2.3 Water quality for groundwater and surfacewater

Water quality status of surfacewater or groundwater directly reflects whether is suitable for drinking, and indicates the cost of water treatment that will produce drinking water. In order to guarantee the water quality of potential waterworks, the water quality improvement effect of RBF was thought of as an additional assurance. Because of limit element of parameter in water quality index for surfacewater and no water quality index for groundwater was developed, Environmental quality standards for surface water (GB3838-2002) (General Bureau of China National Environmental Protection, 2002) and Quality standard for groundwater (GB/T 14848-93) (Quality Standard for groundwater, 1993), water of quality grades I, II and III can be used as drinking water directly. Water of quality grade IV must be treated before it is supplied for drinking. Because higher index values of the quality grade indicate lower quality water, the assigned index values decrease as water quality grades change from I to IV. Water of quality grade V is a negative factor for the suitability of RBF, and its index value is assigned a negative number. This can make the negative water quality factor play a decisive role in the process of suitability evaluation of RBF. The groundwater quality (G) and surface water quality (S) suitability scoring criterion is shown in Table 6.

Table 6. Groundwater quality (G) and surface water quality (S) index value.

G/S	I	II	III	IV	V and Worse than V
Index Value	100	95	90	60	-275

3.2.4 Interaction intensity between surface water and groundwater

A large proportion of RBF waterworks primarily capture surface water; the interaction intensity between surface water and groundwater plays an essential role. Hydraulic Gradient (I) under the Current Condition The hydraulic gradient directly reflects recharge-discharge relationship between surface water and groundwater, and it also indicates recharge-discharge conditions of the interaction zone. A positive hydraulic gradient was defined to represent scenarios in which river water recharges groundwater; similarly, a negative hydraulic gradient indicates that river water is recharged by groundwater. A positive value of hydraulic gradient is beneficial to RBF in most situations; however, a very large value for the hydraulic gradient might mean that riverside groundwater is being exploited intensively or that the interaction between surface water and groundwater is poor, because the very low permeability of aquifer or riverbed will obviously enlarge hydraulic gradient and decrease water exchange intensity. A negative hydraulic gradient indicates that the surface water cannot be induced into the ambient aquifer at present. Nevertheless, a negative gradient might be reversed and to be beneficial for RBF under groundwater exploitation condition. If the present negative hydraulic gradient is excessively small, it may indicate that the permeability of aquifer or riverbed is very poor, and the large groundwater recharge potential from river water should not be expected under any exploitation conditions. The hydraulic gradient suitability scoring criterion is shown in Table 7.

Table 7. Hydraulic gradient (I) suitability evaluation criteria.

I	>10	10-5	0-5	0 to -5	-10 to-5	<-10
Index value	40	80	100	90	80	60

3.2.5 Influence zone width of surface water under the condition of groundwater exploitation (L)

The influence zone by surface water indicates the range of the hydraulic connection between surface water and groundwater. The greater the hydraulic connection range between surface water and groundwater, the superior the RBF site. The possible influence zone (L) was assumed to be equal to the ratio of the aquifer thickness (M) to the hydraulic gradient (I). The suitability index value for the possible influence zone by surface water is shown in Table 8.

Table 8. Index value for the possible influence zone width of surface water under the condition of groundwater exploitation (L).

L	$< \frac{M}{\lvert I\rvert max}$	$\frac{M}{\lvert I\rvert max} to \frac{M}{\lvert I\rvert average}$	$\frac{M}{\lvert I\rvert average} to \frac{M}{\lvert I\rvert min}$	$> \frac{M}{\lvert I\rvert min}$
Influence intensity index value	Strong 100	Medium 80	Weak 60	None 30

3.2.6 Permeability of riverbed layer (P)

Riverbed permeability indicates the exchange capacity between surface water and groundwater. Riverbed permeability is calculated using the hydrogeological cross section of the riverbed obtained from a field investigation as standard. Then, the lithology under the riverbed is analyzed to obtain its permeability, either by measurement or practical experience. The riverbed permeability suitability index value is shown in Table 9.

Table 9. Permeability of riverbed layer (R) suitability scoring criterion.

P (m/d)	>5	1-5	0.5-1	0.1-0.5	0.05-0.1	0.01-0.05	<0.01
Index value	100	90	80	70	60	30	0

3.2.7 Groundwater level

When considering the development and utilization of groundwater resources, groundwater level is a primary concern because it indicates the cost of building RBF wells. If the groundwater level is too far below the ground surface, it may be in a highlands area or in a cone of a groundwater depression. In those places, the extraction of groundwater requires more energy. The groundwater level index value is shown in Table 10. Because groundwater level is strongly influenced by regional characteristics, this standard should be adapted to different hydrogeology conditions.

Table 10. Groundwater depth (D) index value.

D (m)	<5	5-10	10-15	15-20	20-25	25-30	>30
Index value	100	90	80	70	60	30	15

3.2.7 Suitability Index

According to the evaluation index system created above, the complex suitability index for a potential RBF site can be calculated by weighted summation using Eq. [1].

$$A= XK \times WK + XM \times WM + XQ \times WQ + XG \times WG + XS \times WS + XI \times WI + XL \times WL + XR \times WR + XD \times WD \quad [1]$$

In Eq. [1], A is the suitability index of a potential RBF sites, X is the index value of individual indices as defined in Tables 3–10 and W is the weight of each corresponding index as defined in Table 2. The RBF suitability was then classified into five grades according to the suitability index value (Table 11).

Table 11. RBF suitability class.

Suitability Index Value	Class	Suitability Evaluation
90-100	I	Excellent suitable areas
80-89	II	Good suitable areas
70-79	III	Moderate suitable areas
60-69	IV	Poor suitable areas
<60	V	Unsuitable areas

In areas for which RBF suitability grades are between I and III, water quality satisfies human drinking water requirements and does not need treatment, and water quantity is adequate. Furthermore, the exchange between river water and groundwater is intensive, the water quantity and water quality of RBF is guaranteed, and there are good development and utilization conditions of groundwater resources. In short, areas in grades I–III are suitable for RBF. In areas for which the RBF suitability grade is IV, either water quality does not satisfy drinking water requirements directly or the water recharge is insufficient. After water treatment and limited exploration, such areas may be suitable for limited-scale RBF waterworks. Areas in grade V are unsuitable for RBF works because of unacceptable water quality, high water treatment costs or insufficient water recharge to sustain extraction at the required rate and volume.

4 RESULTS AND DISCUSSIONS

The various index values were integrated using Eq. [1] to determine the overall suitability of locations at the study area for RBF works. Nine typical points were selected to show the characteristics of each class of suitability (Table 12). Based on the multi-criteria analysis, the suitability of many locations in the study area was classified as grade I and II and should be suitable for locating RBF works.

Table 12. All single index values and scores for three sites.

Index	Muda River		Linggi River		Langat River	
	Value	Index Value	Value	Index Value	Value	Index Value
K, hydraulic conductivity	80 m/d	90	53.1	80	63.64 m/d	90
D, Aquifer thickness	17.9 m	80	7.5	70	17.1	80
R, surface runoff	432×10^4m3/day	100	518 x 10^4 m^3/day	100	164 x $10^4 m^3$/day	100
G, Groundwater quality	III	90	II	95	II	95
S, Surfacewater quality	II	95	III	90	III	90
I, Hydraulic gradient	-0.2	90	-0.1	90	- 0.035	90
W, Influence zone	strong	100	strong	100	strong	100
P, Permeability of riverbed layer	1.9 m/d	90	0.3 m/d	70	1.2 m/d	90
D, groundwater level	2.2	100	2	100	1.6	100
Total Index value		92.80		88.33		92.80
Class		I		II		I

5 CONCLUSIONS

Many important factors affect the site selection for RBF works such as groundwater and surface water quantity, current water quality situation, hydraulic interaction degree and exchange relationship between groundwater and surface water. In this research, a multi-criteria index system was developed for assessment of RBF site suitability. The RBF index system was based on a detailed analysis of physical geography and geological and hydrogeological conditions (which were considered to be the main influential factors of RBF), as well as on the development and utilization of water resources and water demand. Value index criteria based on specialist marking methods were used to determine weighting coefficients and weighted scores. The evaluation method was integrated will put into the spatial analysis features of GIS to determine the distribution of suitable areas for RBF works. However, this research still has some limitations that must be mentioned here and will be studied further.

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RESEARCH ON THE HEALTH DIAGNOSE OF WATER CONSUMPTION AND THE REGULATING MODEL OF HIGH EFFICIENT WATER USE ON LARGE WATER SHORTAGE CITY IN BEIJING CITY

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ABSTRACT

With the development of mega cities, the scale of population continues to expand, hence the problem of water shortage is getting more and more important. In this paper, the analysis of water use in Beijing city is analyzed, the status of high efficiency water use is diagnosed, the efficiency of urban household water use is comparatively analyzed, and the regulating model of high efficient water use on Beijing city is proposed. The results show that Beijing city is facing the rapid increasing in the total amount of water, water use structure is gradually rigid. Due to the higher water efficiency in Beijing city, the structural water saving potential is gradually reduced, the management of urban household water use turns out to be the focus of water-saving. The water habit of residents is the important factors that affect the urban household water use. Finally, water regulation models are proposed, including the strict control of population growth, the reduction of the threshold of the price ladder, the encouragement of consumer to undertake the water price of public service industry, and the development of water use management mechanism on the red line of industry efficiency.

Keywords: mega cities; health diagnose; high efficient water use; regulating model; Beijing.

1 INTRODUCTION

Beijing is one of the world's largest and most important cities in China. Beijing, the capital of China, its resident population in 1999 to 2013 grew from 13.63 million to 21.15 million, an increase of 55%. Beijing's future population may be nearly 30 million and it will become the core of the 100 million population urban agglomeration (Zhang et al., 2011). Since 1949, Beijing’s urban area has increased by about 17 times its original size and it is the China’s second largest city today, in terms of population, after Shanghai (Zhang et al., 2010). Beijing bears most of the problems that are faced by megacities (Duan, 2005; Qiao et al., 2013): the rivers are massively polluted, the groundwater is overexploited, and the shortage on water storage. Water resources per capita in Beijing is only 100 m^3 (http://news.xinhuanet.com/2011-05/15/c_121417803.htm), due to the insufficient water supply. Groundwater is an important component of Beijing's water supply, accounting for 70 to 80% of the total water supply. Groundwater levels have been declining due to overexploitation of groundwater (Jia et al., 2011). In the current and future period of time, the construction of the world city’s development strategy, the realization of the Beijing-Tianjin-Hebei regional and economic integrated development strategy, creating a "capital economic circle", the national ecological civilization construction and other national strategies on water security in Beijing has put forward higher requirements. In this paper, the analysis of water consumption in Beijing megalopolis was carried out. The status of high efficient water use was diagnosed and the efficiency of domestic water consumption was analyzed. Finally, the authors put forward some suggestions on the regulation and control of high efficient water use in Beijing, besides providing some methods and path guidance for the sustainable and healthy development of water use in Beijing. The structural water-saving potential is gradually reduced, the domestic water management is the water-saving key, and the water habit of residents is an important factor affecting the residents living water.

2 WATER ANALYSIS ON LARGE WATER SHORTAGE CITY IN BEIJING

2.1 Analysis of total water consumption

From 1980 to 2013, the total amount of water used in Beijing has gone through three stages, as shown in Figure 1. As shown, from 1986 to 1992, the water consumption in Beijing city was in the extensive management stage. The population and industry scale were small. The economic development is the theme of the times. Water supply is basically unlimitedly guaranteed. As the total water resources in Beijing were relatively abundant, the supply pressure was very low. From 1992 to 2004, on the other hand, the rainfall in Beijing has decreased as compared to the same period in history, especially after 1999, Beijing was in the dry season. Through a certain water-saving measures, the water use efficiency of industry and agriculture has been improved, and the total water use dropped significantly. However, the size of the population was getting large, the water supply in Beijing began to tense. Since 2004, the rainfall in Beijing has been low and the water-saving potential of industry and agriculture has been continuously compressed. While the population size continued to expand, the domestic water consumption rose sharply, thus the total water consumption in Beijing began to rise, causing the pressure on the total amount of water in the future is huge. Despite the implementation of a more stringent water management system in Beijing, it is difficult to control the continuous increase in the total water consumption. The conflict between water supply and demand is outstanding.

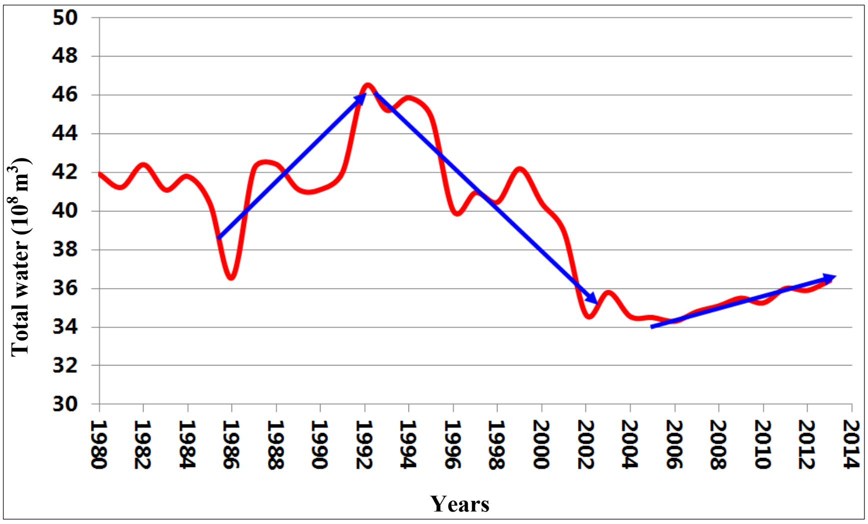

Figure 1. Annual changes in total water use in Beijing, Adopted from Beijing Water Resources Bulletin (1980 - 2013).

2.2 Analysis of water consumption structure

Viewing from the water structure of Beijing (Figure 2), from 1980 to 2013, the water consumption showed "two improvements and two reductions". The industrial and agricultural water use efficiency was increasing and subjected to strict controls, and it showed a downward trend year by year, due to the expansion of the population scale. As the impact of improving the quality of life, the domestic water consumption rigid was increased. In recent years, the environmental water has been paid attention gradually. The water consumption of the river base flow, lake water system, municipal greening and so on increases greatly, and the environmental water quantity surpassed the industrial water consumption for the first time in 2012. In overall, the water use structure in Beijing has two characteristics. First, the total water consumption growth rate has been effectively controlled, despite the huge pressure on water demand. With proper management, the actual growth rate of total water use has been effectively controlled. Second, the water structure tends to be reasonable, the industrial and agricultural water efficiency was generally increasing. Accounting for the declining proportion of total water consumption, the environmental water status has been enhanced by paying more attention to the harmonious development of man and nature. Domestic water was a rigid demand. It was the largest water users, the current control of water consumption, mainly through economic levers and water-saving publicity.

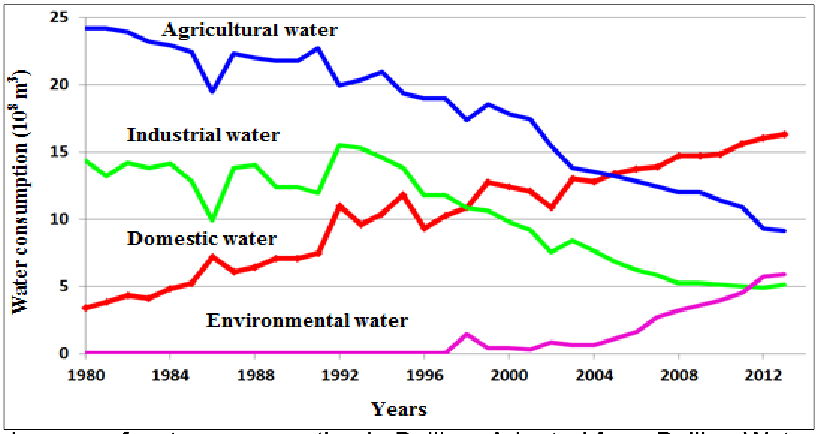

Figure 2. Structural changes of water consumption in Beijing, Adopted from Beijing Water Resources Bulletin (1980 -2013).

2.3 Analysis of water consumption efficiency

(1) Comparative analysis of overall water consumption efficiency

The water consumption per capita in Beijing were compared with other economically developed cities in China, are shown in Figure 3. Among the 14 mega cities listed, the water consumption per capita in Beijing was only higher than that in Tianjin. It can be seen that per capita consumption of water in Beijing was relatively low and the water consumption level was relatively high.

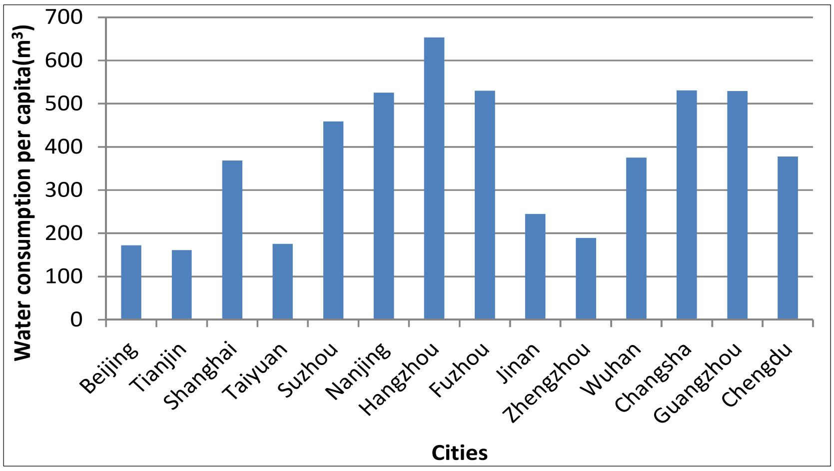

Figure 3. Water consumption per capita in Beijing and other cities , Adopted from China Water Resources Bulletin (2013).

(2) Comparative analysis of domestic water use efficiency

As shown in Figure 4, the urban water consumption per capita in Beijing was higher than that in Tianjin in 2013, indicating that the domestic water use efficiency of Beijing residents was higher. The per capita of urban water consumption in Beijing was 115 L/d, while that in Tianjin was 62 L/d. The difference was significant. The statistics is mainly affected by two factors. One is the effect of floating population in Beijing is far higher than Tianjin, especially the proportion of the floating population living in a relatively long time; second, the actual coverage of public network population and urban population are quite different, For example, the public pipe network in Tianjin covers a population of about three million lower than the urban population.

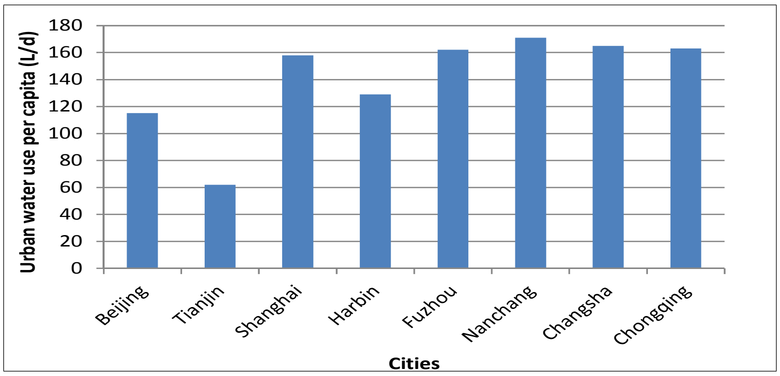

Figure 4. Urban water use per capita in Beijing and other cities, Adopted from China Water Resources Bulletin (2013).

(3) Comparative analysis of industrial water use efficiency

In 2013, Beijing's industrial added value of water consumption per ten thousand yuan was about 15 m³, 65.3% lesser as compared to 41.8 m³ in 2005, or only one-sixth in 2002. With the continuous adjustment and upgrading of industrial structure in Beijing, the industrial water use efficiency has been increasing. Comparing to other cities in China, as shown in Figure 5, Beijing's industrial water efficiency is only lower than Tianjin and Shenzhen. This shows that the overall efficiency of industrial water in Beijing is in the leading domestic level.

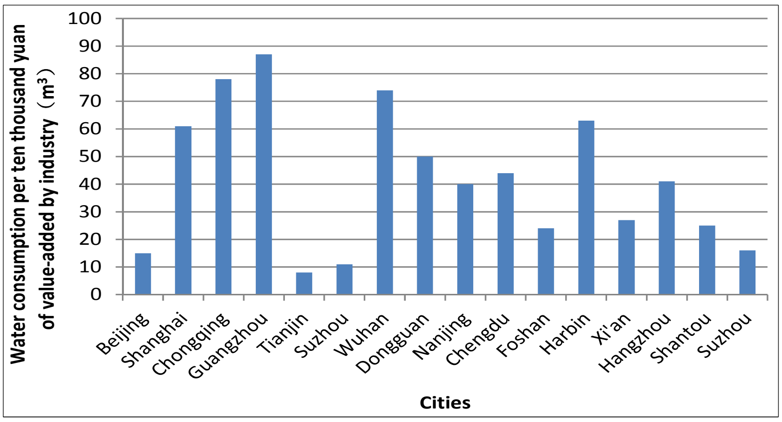

Figure 5. Water consumption per ten thousand yuan of value-added by industry in Beijing and other cities, Adopted from China Water Resources Bulletin (2013).

From the 12 above-scale industrial water use data available in Beijing and Tianjin, as shown in Table 1, it can be seen that the water consumption of Beijing's food industry is much higher than that of Tianjin, it is the focus of industrial water.

Table 1. Water consumption per above-scale industrial production value of Beijing and Tianjin in 2013 Adopted from China Water Resources Bulletin and China Statistical Yearbook (2013).

Above-scale industrial sector	Water consumption per ten thousand yuan in Beijing (m^3)	Water consumption per ten thousand yuan in Tianjin (m^3)
Ferrous metal smelting and rolling processing industry	1.16	2.16
Transportation equipment manufacturing	0.38	0.65
Electronic and communication equipment manufacturing industry	0.94	0.58
Petroleum and natural gas extraction	0.07	0.22
Petroleum processing and coking industries	3.00	2.66
Raw chemical materials and chemical products	1.57	5.57
Metal products industry	0.62	0.01
Coal mining and dressing	0.45	0.81
Electric machinery and equipment manufacturing	0.38	0.80
Food manufacturing industry	7.51	1.18
Electricity, steam and hot water production and supply industry	2.54	12.20
Non-ferrous metal smelting and rolling processing industry	0.61	0.27

(4) Comparative analysis of agricultural water use efficiency

In 2013, the effective use of irrigation water in Beijing has reached 0.701, higher than the national average of 0.52. Farmland irrigation water per mu of water is 313 m^3. Comparing Beijing to other large cities in Figure 6, it can be seen that Beijing's farmland irrigation water per mu of water consumption is low. The overall water-saving space is small, Beijing can work together to promote agricultural water conservation through adjusting irrigated area, coordinating farmland water conservancy construction, land consolidation, comprehensive agricultural development, urban modern agriculture layout and other measures.

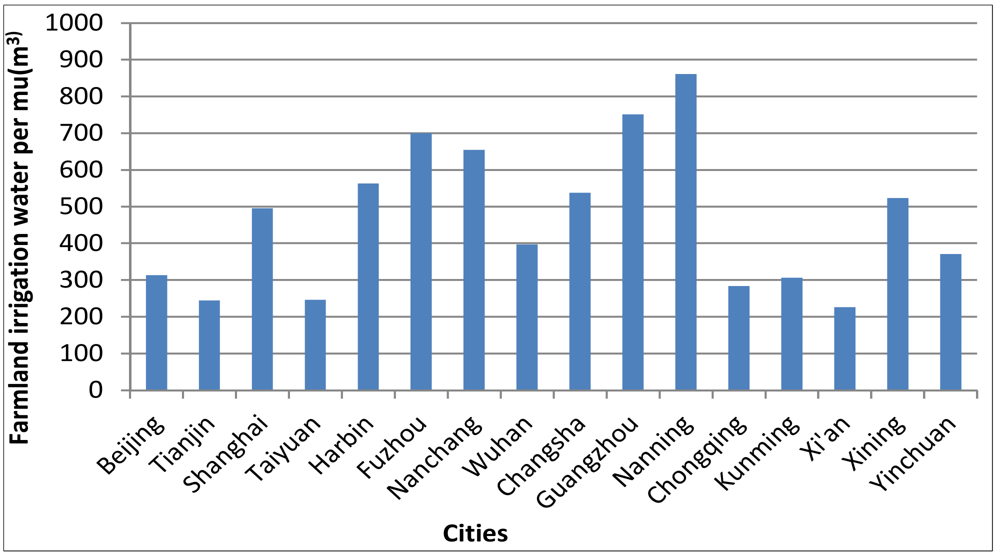

Figure 6. Farmland irrigation water per mu in Beijing and other cities Adopted from China Water Resources Bulletin (2013).

3 DIAGNOSIS OF WATER USE EFFICIENCY IN BEIJING

The industrial water consumption has achieved a year-on-year reduction in Beijing since the industrial enterprises make the water-saving technology better and improve the industrial water recycling rate, under the guidance of Beijing's industrial policy, including the strengthening of industrial restructuring, optimization and upgrading, inhibition of high water consumption industrial development.

In 2000, industrial water consumption exceeded 1 billion m^3 in Beijing and accounted for 26% of the total water consumption. Then, the industrial water consumption in Beijing decreased year by year. In 2013, the city's industrial water consumption felled to 510 million m^3 and the proportion of industrial water reduced from 26% in 2000 to 14% in 2012, indicating that the water structure of Beijing is escalating.

From the point of view of water structure, the traditional high water industries' (in addition to electricity, heat production, supply industry and pharmaceutical manufacturing) production value decreased year by year since 2010, as shown in Figure 7. This indicates that the industrial structure within the industry has also been optimized, and industrial water-saving space and potential is relatively small.

The tertiary industrial water consumption is the main consumption for public use. From the current industrial structure of Beijing's tertiary industry's point of view, the main part of the tertiary industry is the low-use industries, which includes transportation, storage and postal services, information transmission, computer services, software wholesale and retail, finance and other industries, accounting for 66% of the tertiary industry. The tertiary industry's water-saving space and the potential are small.

From the development trend of domestic water use, as shown in Figure 8, with the acceleration of urbanization and the improvement of living standard, the water consumption of Beijing residents will increase in the future. But, the variation trend will change from large to small, and the change of water use is equal to the change of population size that was greater than the change of population size in the past.

These two points reflect the role of water-saving. In the future, the population is still the main factor affecting the water use scale of Beijing residents. However, the elastic coefficient can be further reduced and the change of water consumption will be smaller than the population size by strengthening the water saving.

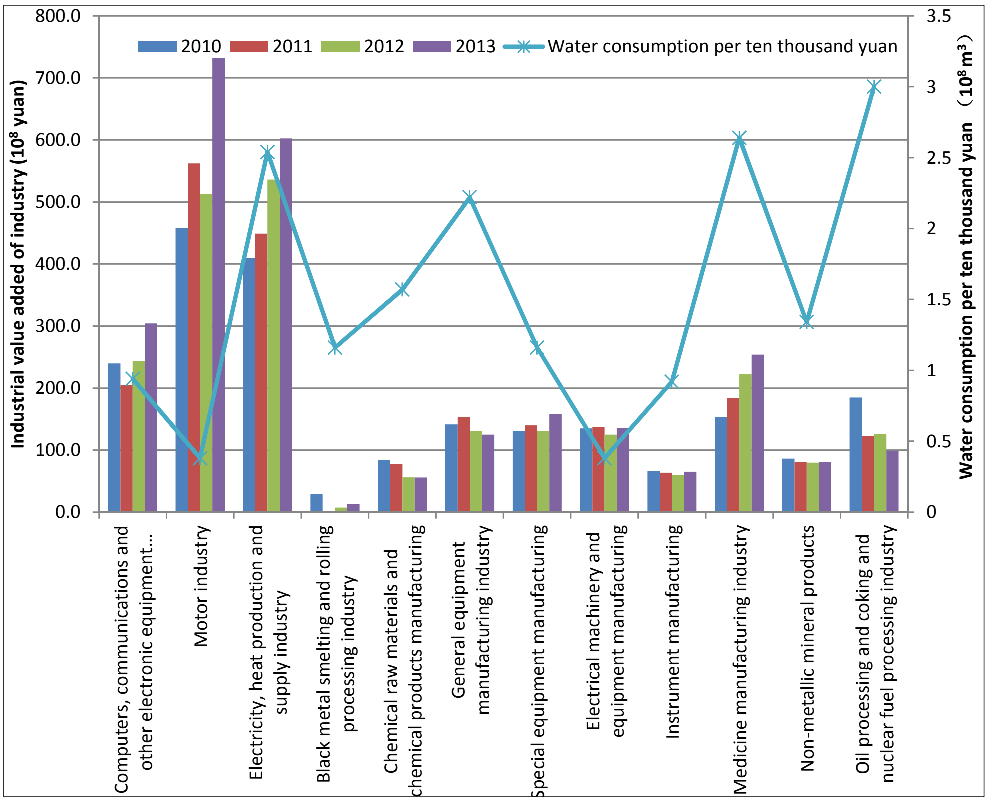

Figure 7. Industrial added value of industry and water consumption per ten thousand yuan of output value in Beijing, Adopted from China Water Resources Bulletin and China Statistical Yearbook (2010-2013).

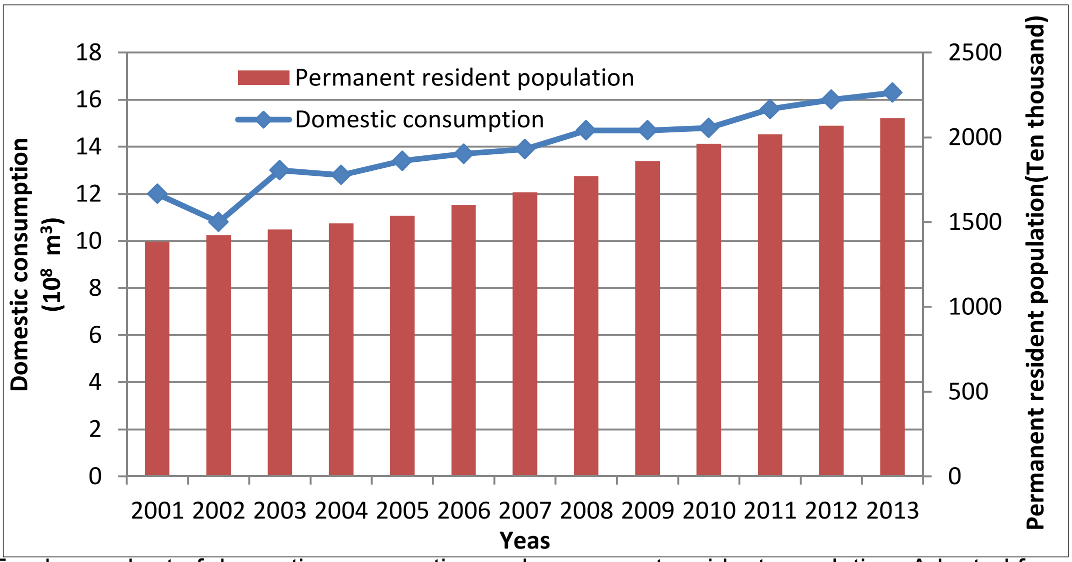

Figure 8. Tendency chart of domestic consumption and permanent resident population, Adopted from China Water Resources Bulletin and China Statistical Yearbook (2001-2013).

With the increase of population and the improvement of demand for public service level and the ecological environment, the consumption of water for public use (including environmental water) increased significantly. In 2013, there was 1.272 billion m^3 water used as Beijing's consumption for public (including environmental water), and the number is 908 million m^3 in 2006, with an average annual growth of 5%. Meanwhile, the share of consumption for public use in total water consumption in the region increased from 26.47% to 34.96%, accounting for 46% of the total domestic water consumption, so the consumption for public use is the focus of water conservation work.

In the composition of public service water use of the center district of Beijing in 2013, the proportion of institutions, schools, hotels, hospitals and office buildings are 19%, 15%, 12%, 7% and 8%, respectively. Business, catering industry, troops, culture recreation business and building operations accounted for 9%, 7%, 2%, 2% and 8%, respectively. Also, the communications and transportation industry accounted for 1%and the last 10% is other uses. From the perspective of public water use structure, institutions, schools and hotels occupy higher proportions of water use.

4 SUGGESTIONS ON EFFICIENT WATER REGULATION AND CONTROL IN BEIJING

4.1 Analysis of total water consumption

The continued expansion of population size and the rapid development of economic social bring the rigid demand of water resources. In "The Beijing city master plan (2004 ~ 2020)", the expected population for 2020 is 18 million. But, the average annual increase is 600 thousand since 2000 and 800 thousand since 2005. The city's permanent population in 2012 has reached 20.69 million, breaking through the schedule objectives ten years in advance. Currently, the average of total water use in Beijing is 3.6 billion m^3. The urban water (mainly for the residents' living water, secondary and tertiary industries in the use of water, urban rivers use of water) accounted for the total water consumption increased to 74% from 51% in 2000, which is a rigid demand. According to the present increasing rate of population at 80 m^3 per capita water, by 2030, there will be a year more than 600 million m^3 water shortage of Beijing's dilemma with only the factor of population growth is considered. The sustained and rapid population growth not only exceeds the load of water resources carrying capacity and the excessive concentration of population but also increase the difficulty of the safe water supply. Therefore, it is necessary to strictly control the population size of Beijing and comprehensively use economic, legal, administrative and other means to control the population agglomeration growth, promote the construction of Beijing economic circle, perfect the docking mechanism of population dispersal, guide the migrant workers to gather in surrounding towns, evacuate the urban area's population density, shift the floating population to the city development zone, which not only reduce the concentrated mining and the pressure of water, but also can reduce the sewage discharge.

4.2 Reduce the levy standard of ladder water price

On May 1, 2014, Beijing adjusted the water prices of resident, non-resident and special industry. For residential water, if the annual water consumption is below 180 m^3, the water price is 5 yuan/m^3. 7 yuan/m^3 for the annual water consumption between 181-260 m^3, and the annual water consumption above 260 m^3 costs 9 yuan/m^3. Although the price of residential water has increased over the past, but the prices of water are still low and can't reflect the scarcity of water resources. In addition, the proportion of water expenditure in household expenditure is getting smaller and smaller. The residential water price was 3.7 yuan/m3 in 2004, 4.0 yuan/m^3 in 2009, and 5.0 yuan/m^3 in 2014. During the same period, per capita disposable income of Beijing urban residents reached 14,000 yuan, 27,000 yuan, and 40,000 yuan, respectively. The increased rate in water prices is significantly lower than the growth rate of disposable income. According to the preliminary estimation, the household water consumption expenditure is reduced from 1.3% to 0.6% in ten years' time(Jiang, 2009), and the proportion of water expenditure is getting lower, while that of the developed countries is 1% ~ 3% (Zhang et al., 2007).

In the questionnaire of household water use, the average daily water consumption of residents whose per capita income are less than 20,000 yuan is as high as 143.06 L/(person•d), which is higher than the highest value of the per capita water consumption of Tianjin (95.51 L/(person•d)). The residents of Beijing of the bath frequency are mainly concentrated in the 3 to 5 times a week, which was not much difference with Tianjin. But, the water consumption for one time of Beijing's residents was far greater than that of people in Tianjin. In Beijing, the average proportion of hand washing in all samples was only 29.23%, while that of Tianjin was 41.4%. It is calculated that the average score of water-saving degree in Beijing's residents was 2.6 points, while that in Tianjin was 2.8 points, which fully shows that the consciousness of water-saving among the residents of Beijing is relatively weak.

In view of the weak consciousness of water-saving among the residents in Beijing and the present situation of the low water price guide, Beijing should study the price of water as soon as possible to reduce the levy standard of ladder water price, increase the proportion of water expenditure to household expenditure, establish the multi-water and multi-fee ladder water pricing mechanism, formulate a reasonable water price and stimulate the enthusiasm of users' water-saving; make a high standard of water-saving equipment list, build a system of appliances for water saving water subsidies, guide the public to purchase the most advanced water-saving equipment; improve the residents' water-saving consciousness, strengthen the residents of domestic water cycle utilization rate, so that the residents fully realize the importance of water saving, guide the residents to develop a good living habits of cherishing water, and using water in reasonable and scientifically.

4.3 Implement the management mode that water consumers bear the water bill of the public service industry

In 2013, Beijing's public service water accounts for 46% of the total domestic water consumption. In terms of the structure of public water, authority institutions, schools, and hotels occupy a higher proportion of water. Aiming at the industry of public water is diverse, and the main body of the consumption subject is separated from the water fee. Beijing should explore to establish the water-saving management model, in which the water bill is undertaken by consumers and select typical industries to carry out pilot projects.

Beijing has more than 50 government units that promote the work of water-saving unit creating. The schools implement the water measurement of IC card. For example, after the Heilongjiang University uses the card-type shower, the average bath time reduces from 50 min to 10 min of actual water using time. At the same number of baths per day and the same fee that students pay for baths, per capita water drops from 250 L to 80 L. The monthly water consumption drops from 30 thousand t to 9.6 thousand t, saving up to 20,400 t/month. The water-saving benefits are significantly. Beijing should continue to push forward the use of IC card metering water in public service industries, such as hotels, hospitals and so on. The pattern that consumers bear the water fee may construct the environment and policy to promoting consumers spontaneous to save water.

5 CONCLUSIONS

The water consumption in Beijing is increasing, while the structure is gradually rigid and the water use efficiency is high. The structural water-saving potential is gradually reduced, the domestic water management becomes the water-saving key, and the residential water habit is an important factor that affects the residents' living water. Water is needed for economic development in the megacities and is constrained by the shortages of resource and environmental protection. At the macro level, the efficient use of water resources should be based on the basin and regional water resources carrying capacity, in accordance with the rational allocation of regional water resources requirements. At the same time, it is necessary to establish a sustainable concept of "water production" and "appropriate water development", further establish an economic structural system compatible with the carrying capacity of water resources. It is also very important to carry out industrial water screening, set the threshold of entry, and promote the micro-water saving technology in sub-sectors, and ultimately promote the coordination of population, resources, environment, economic and social development. In order to promote efficient water use, we should play the role of ternary subject and form a linkage mechanism of "government regulation" - "market guidance" - "individual participation", and to establish an environment and policy to promote water users' spontaneous water saving, including the strict control of population growth, the reduction of the starting price of ladder tariff standards, the implementation of the consumer to bear the public service industry water management model.

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CLARIFICATION OF WATER SOURCES THROUGH RIVERBED FILTRATION (RBEF) MODEL: TURBIDITY, COLOUR AND SUSPENDED SOLIDS REMOVAL

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ABSTRACT

Although rarely studied, riverbed filtration (RBeF) is one of the best methods for establishing water supply systems in developing countries. Riverbed filtration acts as a pre-treatment system at the water treatment plant. Hence, RBeF must be studied extensively for the sake of its many benefits in terms of water production. The development of a physical model of riverbed filtration (RBeF) system in the laboratory is one of the studies that can be done in order to determine the efficiency of this system. Thus, a series of physical model experiments in a 0.81 m^3 sandbox were conducted to evaluate the performance of a riverbed filtration system before it can be applied at the site. In this study, the performance of the proposed riverbed filtration (RBeF) model to remove turbidity, colour and suspended solids from water sample was determined. The percentage removal was determined with three different parameters: flowrate, concentration of contaminants and depth of filter media. Laboratory results show that the percentage removal of turbidity is between 62.6% and 93.9%. For the percentage removal of colour, it is between 24.3% and 87.4%. Lastly, for the percentage removal of suspended solids, it is between 70.6% and 97.4%. The results also show that the depth of the filter media plays an important role and influenced the percentage removal of these three studied parameters. The higher the depth of filter media used, the higher the percentage removal of turbidity, colour and suspended solids. This riverbed filtration (RBeF) has a good potential for further research and future application.

Keywords: Riverbed filtration; physical model; turbidity; colour; suspended solids.

1 INTRODUCTION

One of the alternatives for a good water intake is through riverbed filtration (RBeF) system. Riverbed filtration is a natural system where it involved inflow of river water to the underground aquifer induced by the hydraulic gradient (Schön, 2006). This system acts as a pre-treatment system before the next step of treatment is taken at the water treatment plant. This system has been introduced to improve the water intake process. Water intake is directly changed from water surface to water intake by single well connected to one or several collectors dug in the riverbed and not in the aquifer (Blavier et al., 2014). Bed sediments and aquifer materials act as natural filters that remove contaminants as water percolates through the riverbed (Vozza, 2013). When the water moves through the riverbed and aquifer materials, most biological and chemical contaminants are removed and the temperature of the water will equilibrate (Kim et al., 2008). Its advantages over the traditional water treatment method make riverbed filtration (RBeF) system a better choice to improve the removal capacity and reducing the total cost (Shamrukh and Abdel-Wahab, 2011). Many water utilities in the United States use riverbed filtration system by using collector wells with lateral pipes lying horizontally beneath the riverbed (Kim et al., 2008). Figure 1 clearly shows the schematic representation of a riverbed filtration (RBeF) system. According to Dalai and Jha (2014), several parameters such as quality of river water, source of pollution, flow velocity and bed load characteristics, seasonal of river flow and stability of the river channel may affect the performance of the riverbed filtration system. Riverbed clogging can also become a challenge that prevents optimal filtration (Vozza, 2013). A riverbed filtration model in which the physical model was used is an option in order to investigate the performance of the riverbed filtration system in the laboratory. According to Rushton and Brassington (2013), a limited number of laboratory investigations have been carried out on horizontal wells (riverbed filtration systems). The physical model is most commonly referred to simply as a model, a larger or smaller copy of an object. A physical model is a model where the physical characteristics are similar to the physical characteristics of the current system being modelled. It is important to emphasize that a physical model is not the real, but it can help researchers to understand the real system more. Thus, the development of a physical model of the riverbed filtration system was done in this study. The advantage of physical model is that it can be easily manipulated by changing the studying parameters.

The aim of this research is to achieve objectives for water clarification using a riverbed filtration model. In order to ascertain this aim, the objectives are as followed:

a) To identify the soil characteristics at Kampung Semuba, Pasir Mas, Kelantan.
b) To determine the performance of a riverbed filtration model to remove turbidity, colour, and suspended solids from synthetic water sample.
c) To determine the optimum condition of a riverbed filtration model for different flowrates, concentrations of contaminants and depths of filter media.

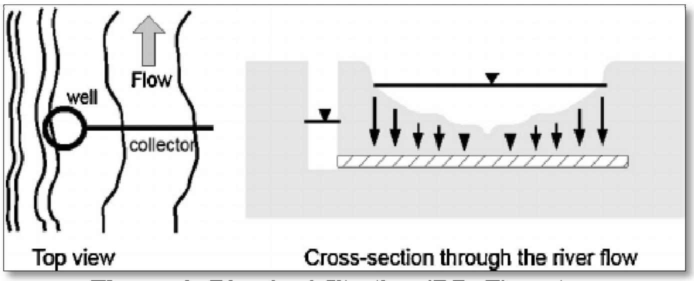

Figure 1. Riverbed filtration (RBeF) system.
(Blavier et al., 2014)

2 PROJECT SITE

In this study area, Kampung Semuba, Pasir Mas, Kelantan was selected as a study area where the source of raw water comes from Kelantan River as in Figure 2. Kelantan River is the major river in Kelantan, Malaysia. During flood season, Kelantan River will overspill its bank, especially during the months of November to February. Flood in the state of Kelantan also affects its neighbouring states, specifically Terengganu and Pahang (Baharuddin et al., 2015). When a flood occurs, river water will overflow more extensively and erosion of the river bank will occur. This will lead to an increase in the concentration of contaminants of water sources. Also, during flood season, the demand of clean water increases and less clean water obtained during this season while there is a need for a safe drinking water. According to Adlan et al. (2015), the river bank/bed filtration was proposed to take advantages of natural attenuation of turbid water and free from the effects of flooding. This system can also optimise the water demand need, especially during flood season where Kelantan River is the source of water for water treatment plant.

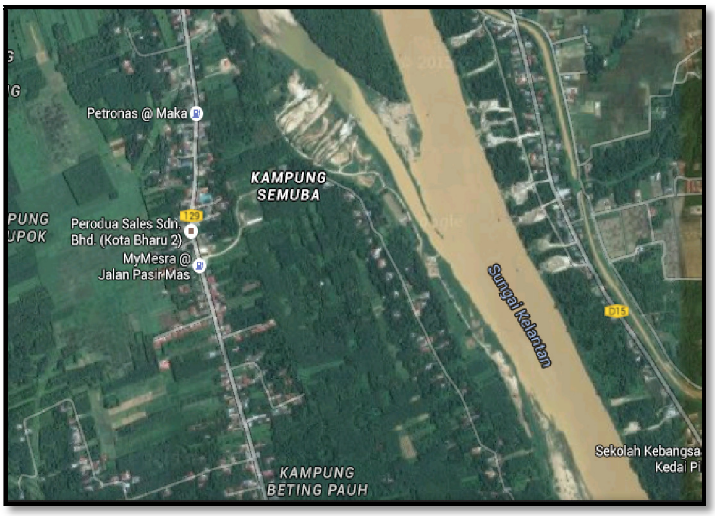

Figure 2. Kampung Semuba, Pasir Mas, Kelantan.

3 DATA COLLECTION PROGRAM

The riverbed sample from Kampung Semuba, Pasir Mas, Kelantan was used in this study and their soil characterisation were examined in the laboratory. However, raw water from this area cannot be taken out to the School of Civil Engineering, Universiti Sains Malaysia due to the cost of long distance to transfer the water sample and huge volume of water sample to run the physical model. Thus, the synthetic water from mixing of soil was produced to replace the raw water used in this experiment. First of all, the soil characterisation of riverbed soil samples from Kampung Semuba, Pasir Mas, Kelantan must be carried out. The water quality of Kelantan River was also identified through previous research. Soil characterisation can be divided into three parts: soil classification, particle size distribution and also permeability. Soil classification was done according to U.S. Department of Agriculture (USDA) system and Unified Soil Classification System (USCS) (Das, 2010). For particle size distribution, the sieve analysis and hydrometer sedimentation analysis were done. Sieve analysis was done for particle sizes larger than 0.063 mm in diameter while hydrometer sedimentation was done for particle sizes smaller than 0.063 mm. For permeability, the focus was on the constant head test. To run the analysis, a series of physical model experiment in a 0.9 m (length) x 1.5 m (height) x 0.6 m (width) sandbox was conducted to evaluate the performance of a riverbed filtration model to provide treated water sample. The physical model (Figure 3) was made using Perspex material in rectangular shape. This physical model was designed based on the description and the principle of riverbed filtration system at the site where it involved the inflow of river water to the underground aquifer induced by hydraulic gradient. The water sample to be purified was passing through the riverbed of the bottom of the physical model. Thus, at the bottom of this physical model, gravel and river sand will be put to act as a filter media and the water sample will infiltrate through the filter media in order to treat it. At the bottom of this physical model, a pipe collector with the diameter of 76 mm (3 inch) was installed. Basically, the pipe collector will have a certain opening size to transfer the treated water through the system. In this study, the opening size of this pipe collector is 0.02 m^2. The most important part of this experiment is to determine the performance of a physical model of a riverbed filtration system in removing contaminants from water sample that is synthetic water from mixing of soil. Thus, for data collection, the water quality measurements of turbidity, colour and suspended solids were done before and after running the physical model. The optimum condition of this system was identified for different flowrates, concentrations of contaminants and depths of filter media used.

Figure 3. Riverbed filtration model.

Table 1 shows the summary of soil characteristics for 8 m soil samples. Based on the soil characteristics obtained, it can be concluded that the aquifer adjacent to Kelantan River at Kampung Semuba, Pasir Mas, Kelantan has the potential for the development of riverbed filtration (RBeF) system. Study of sand and gravel is very important to determine the favorable or unfavorable conditions to establish a riverbank/bed filtration system at any place (Sharma et al., 2014). Adlan et al. (2015) in their research also verified that this site (Pasir Mas, Kelantan) is suitable for the riverbank/riverbed filtration due to the presence of sand and gravels that come from granite and quartz.

Table 1. Summary of results of soil characteristics.

Coefficient of uniformity (C_u)	4.088 – 19.744
Coefficient of curvature (C_c)	0.548 – 1.635
D_{10} (mm)	0.055 – 0.516
D_{30} (mm)	0.179 – 0.996
D_{50} (mm)	0.651 – 1.925
D_{60} (mm)	1.077 – 3.068
Soil classification (USDA)	Sand, loamy sand
Soil classification (USCS)	Poorly graded sand with gravel, well-graded sand, poorly graded sand, well-graded sand with gravel, well-graded sand with silt.
Fine soil classification	Silt low (ML)
Majority of soil type	Sand
Permeability (cm/s)	10^{-2} to 10^{-3}
Drainage classification	High
Graded	Well and poor
Type of grading	Normal
Colour	White grey, brown, grey

Figure 4 and Figure 5 show the difference of turbidity, colour and suspended solids after going through physical model experiment at 0.75 m and 1.0 m depth. The difference in the depth of filter media used in this physical model experiment affects the final reading of contaminants. Based on the results, it can be seen that it is easy to remove contaminants when the depth of filter media is high. Table 2 summarises the final reading of turbidity, colour and suspended solids after going through the riverbed filtration system at two different depths. The difference in the depth of filter media used in this physical model experiment affects the final reading of contaminants. Based on the results, it can be seen that it is easy to remove contaminants when the depth of filter media is high. Thus, this result has proved that the removal efficiency is highly dependent on depth of filter media used as mentioned by Guchi (2015). The final reading of contaminants after going through 1.0 m depth of riverbed filtration model is lower as compared to the final reading of contaminants after going through riverbed filtration model at 0.75 m depth.

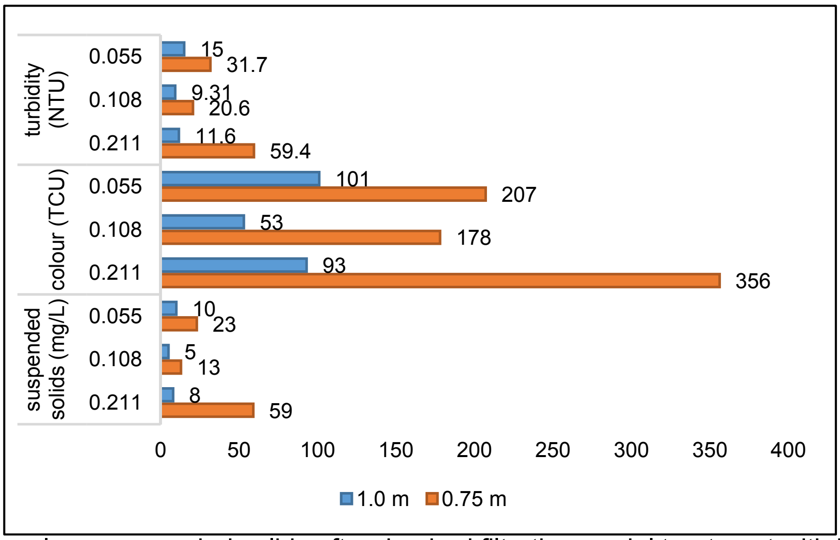

Figure 4. Turbidity, colour, suspended solids after riverbed filtration model treatment with high contaminants.

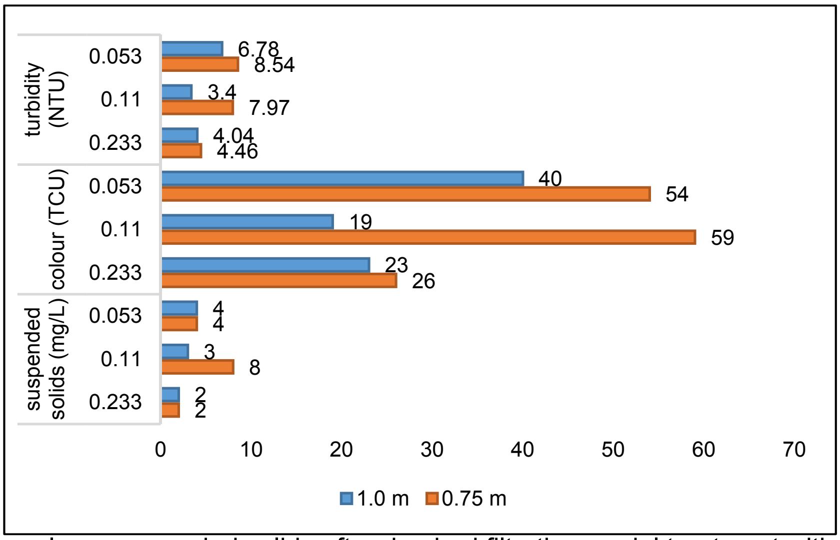

Figure 5. Turbidity, colour, suspended solids after riverbed filtration model treatment with low contaminants.

Table 2. Results for turbidity, colour and suspended solids after riverbed model treatment.

Concentration of contaminants	Depth (m)	Reading Turbidity (NTU)	Colour (TCU)	Suspended solids (mg/L)
High	1.0	9.31 – 15.0	53 – 101	5 - 10
	0.75	20.6 – 59.4	178 - 356	13 – 59
Low	1.0	3.4 – 6.78	19 - 40	2 – 4
	0.75	4.46 – 8.54	26 - 59	2 - 8

Table 3 shows the results for the percentage removal of turbidity, colour and suspended solids at 1.0 m depth at low and high contaminants. The percentage removal of turbidity is higher by up to 93.9%. At high turbidity, the percentage removal is between 89.5% and 93.9% where 93.9% removal occurs at 0.111 L/s. On the other hand, at low turbidity, the percentage removal is between 75.5% and 88.9% where 88.9% removal occurs at 0.226 L/s. In this research, the percentage removal of colour is higher by up to 87.4%. At high concentration of colour, the percentage removal is between 77.8% and 87.4% where 87.4% removal occurs at 0.111 L/s. On the other hand, at low concentration of colour, the percentage removal is between 57.2% and 79.5% where 79.5% removal occurs at 0.226 L/s. The percentage removal of suspended solids is higher by up to 97.4%. At high suspended solids, the percentage removal is between 94.5% and 97.4% where 97.4% removal occurs at 0.111 L/s. On the other hand, at low suspended solids, the percentage removal is between 86.2% and 96.6% where 96.6% removal occurs at 0.226 L/s. It can be concluded that at 1.0 m depth, the average flowrate (0.111 L/s) is essential in order to remove high concentration of contaminants and high flowrate (0.226 L/s) is suitable to remove low concentration of contaminants. This physical model of riverbed filtration (RBeF) system can easily remove turbidity, colour and suspended solids at high and low concentrations of contaminants at 1.0 m depth.

Table 3. Percentage removal of contaminants at 1.0 m depth.

	Percentage removal (%)					
Depth (m)	1.0					
Flowrate (L/s)	Low		Medium		High	
	0.056	0.051	0.111	0.109	0.205	0.226
Concentration of contaminants	High	Low	High	Low	High	Low
Turbidity (NTU)	89.5	75.5	93.9	82.4	92.3	88.9
Colour (TCU)	77.8	57.5	87.4	57.2	80.0	79.5
Suspended solids (mg/L)	94.5	91.1	97.4	86.2	95.7	96.6

Table 4 shows the results for the percentage removal of turbidity, colour and suspended solids at 0.75 m depth at low and high contaminants. The percentage removal of turbidity is higher by up to 92.0%. At high turbidity, the percentage removal is between 62.6% and 86.2% where 86.2% removal occurs at 0.105 L/s. On the other hand, at low turbidity, the percentage removal is between 82.6% and 92.0% where 92.0% removal occurs at 0.111 L/s. The percentage removal of colour is not consistent, but the higher percentage removal can be up to 81.7%. At high concentration of colour, the percentage removal is between 24.3% and 56.0% where 56.0% removal occurs at 0.053 L/s. 24.3% removal occurs at high flowrate, which is 0.217 L/s. On the other hand, at low concentration of colour, the percentage removal is between 63.6% and 81.7% where 81.7% removal occurs at 0.111 L/s. For the removal of suspended solids, the percentage removal of suspended solids is higher by up to 95.1%. When the concentration of suspended solids is high, the percentage removal is between 70.6% and 92.9% where 92.9% removal occurs at 0.105 L/s. On the other hand, at low suspended solids, the percentage removal is between 91.8% and 95.1% where 95.1% occurs at 0.240 L/s. Overall, the percentage removal of turbidity and suspended solids is higher at 0.75 m depth of filter media. However, the percentage removal of colour is not consistent, but it can still achieve the highest percentage removal until up to 81.7% when the concentration of contaminants is low. Thus, this physical model of riverbed of filtration (RBeF) system seems to be suitable to remove turbidity and suspended solids, whether at high or low concentration of contaminants, but it can only achieve higher percentage removal of colour when the concentration of contaminants is low. It can be concluded that the average flowrate, which is 0.105 L/s is essential in order to remove high concentration of turbidity and suspended solids. The low flowrate, which is 0.053 L/s, is suitable to remove high concentration of colour at 0.75 m depth of filter media. Besides that, at average flowrate, which is 0.111 L/s, it is essential to remove low concentration of turbidity and colour, while the high flowrate at 0.240 L/s is suitable to remove low suspended solids at 0.75 m depth.

Table 4. Percentage removal of contaminants at 0.75 m depth.

	Percentage removal (%)					
Depth (m)	0.75					
Flowrate (L/s)	Low		Medium		High	
	0.053	0.054	0.105	0.111	0.217	0.240
Concentration of contaminants	High	Low	High	Low	High	Low
Turbidity (NTU)	77.5	82.6	86.2	92.0	62.6	87.1
Colour (TCU)	56.0	63.6	50.7	81.7	24.3	74.2
Suspended solids (mg/L)	88.2	91.8	92.9	94.2	70.6	95.1

4 CONCLUSIONS

Different flowrates used in this experiment does not influence the percentage removal of turbidity, colour and suspended solids as the percentage removal for three parameters: turbidity, colour and suspended solids is high at 1.0 m depth. At 0.75 m depth, the performance of this physical model is very excellent, especially when the concentration of contaminants is low. However, when high concentration of contaminants was used, it is difficult to remove contaminants especially the colour. The percentage removal of colour at 0.75 m depth is unfavorable when high flowrate was used. There is no problem to remove turbidity and suspended solids at this depth. In overall, through this experiment, the depth of filter media plays an important role to remove contaminants through this natural system. For a good performance of riverbed filtration system, the deeper the depth of filter media used, the better the system. As compared to the column experiment, the percentage removal of contaminants is higher when used this physical model because of the big dimension used when designing it.

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DESIGN OF OPTIMAL WATER DISTRIBUTION SYSTEMS USING WATERGEMS: A CASE STUDY OF SURAT CITY

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ABSTRACT

Since ancient times, man has tried to reside beside source of water for its easy availability. But with the increase in population, the residence of the population near the water source becomes difficult day by day and thus man has started residing at a location away from water source. Water distribution systems are designed with an objective of minimizing the overall cost while meeting the water demand requirements at adequate pressures. However, during operations of water supply systems, cases of pressure drops, leakages and contamination occur and the main challenge is the lack of a simple tool to accurately predict zones of low pressures and areas where quality is compromised. This study will investigate the operations of Punagam area Water Distribution system in Surat city in terms of pressure variations from the Treatment Works to the consumer points using WATERGEMS V8i software. The WATERGEMS V8i programme analyses the pressure at each node, track the flow of water in each pipe and height of the water in each tank during simulation. After simulation of existing water distribution network, results are presented in various forms and compared with the field actual data. This paper covers the water scarcity problems to consumer and the problem of leakage in the distribution system in particular with an explanation of its causes and its impact on various aspects of life and a clarification of the possibility of effectively using of geographic information systems to contribute in the management of this problem. The results obtained verified that the pressures at all junctions at all pipes are feasible enough to provide adequate water to the network of the study area. Simulated water pressure did not vary significantly with the actual values indicating that the pipes still had their hydraulic capacities even though some sections of the network need augmentation.

Keywords: Hydraulic simulation; pipe network; water demand; WATERGEMS.

1 INTRODUCTION

Water is a vital element for living and is an important component and also a key element for the socio-economic development of a country. A water distribution system is an essential infrastructure in the supply of water for domestic as well as industrial use. It connects consumers to sources of water, using hydraulic components, such as pipes, valves, pumps and tanks. The design of such systems is a multifarious task involving numerous interrelated factors, requiring careful consideration in the design process. Important design parameters include water demand, minimum pressure requirements, topography, system reliability, economics, piping, pumping and energy use. The primary goal of all water distribution system engineers is the delivery of water to meet the demands on quantity and pressure. Unfortunately, as a water distribution system ages, its ability to transport water diminishes and the demands placed upon it typically increase. In addition to the unsatisfactory performance of a deteriorated network, there are direct economic impacts of a failing system.

Water distribution system, hydraulic infrastructure consisting of elements such as pipes, tanks, reservoirs, pumps and valves etc. is crucial to provide water to the consumers. Elements of a distribution system include distribution mains, arterial mains, storage reservoirs and system accessories (valves, hydrants, mainline meters, service connections, and backflow preventers). Distribution mains are the pipelines that make up the distribution system. Their function is to carry water from the water source or treatment works to users.

Water distribution system can be divided into two main parts: (i) Intermittent System: In this system, water is supplied at regular intervals throughout the day. Water may be supplied for a few hours in the morning or in the evening. Due to some negative pressure, the quality of water is not so good compared to continuous water supply system. This system may cause serious risk to health as a result of ingress of contaminated ground water into the distribution system; (ii) Continuous system: In this system, the distribution system remains continuously pressurized so that no contaminated ground water can enter into the water pipelines even there are some small leakages in the system.

Therefore, inspection, control and planned maintenance and rehabilitation programs are necessary to properly operate existing water distribution systems. There is still not a convenient evaluation for the reliability of water distribution systems. Traditionally, a water distribution network design is based on the proposed street plan and the topography. Using commercial software, the modeler simulates flows and pressures in the network and flows in and out to/from the tank for essential loading.

The primary task for water utilities is to deliver water of the required quantity to individual customers under sufficient pressure through a distribution network. The distribution of drinking water in distribution networks is technical challenge both in quantitative and qualitative terms. It is essential that each point of the distribution network be supplied without an invariable flow of water complying with all the qualitative and quantitative parameters. The water supply in most Indian cities is only available for a few hours per day, pressure is irregular, and the water is of questionable quality. Intermittent water supply, insufficient pressure and unpredictable service impose both financial and health costs on Indian households. (Bhave et al., 1983). Leakage hotspots are assumed to exist at the model nodes identified. For this study area Punagam area of Surat City has been identified and the network model for the area under consideration will be prepared and studied for water losses.

2 OBJECTIVES

To assess the performance of Water Distribution Network of Punagam area of Surat City using hydraulic simulation software i.e. WATERGEMS V8i and to address any improvements required in existing network and the mode of operation, in order to improve the quantity of water distributed to the consumers.

3 STUDY AREA

Surat is situated between latitude 21° 06' to 21°15' N and longitude 72°45' to 72°54' E, on the bank of river Tapi and having coastline of Arabian Sea on its west. Surat falls in Survey of India map number 46C/15, 16.The Tapi River receives several tributaries on both the banks and there are 14 major tributaries having length more than 50 km. On the right bank, 4 tributaries namely Vaki, Gomai, Arunavati and Aner join the Tapi River. On the left bank, 10 important tributaries namely the Nesu, Amaravati, Buray, Panjhra, Bori, Girna, Waghur, Purna, Mona and Sipna drain into the main river channel. The drainage system on the left bank of the Tapi river is, therefore, more extensive as compared to the right bank area. The Purna and Girna, the two important left bank tributaries, together account for nearly 45 % of the total catchment area of the Tapi River. The Tapi river, the second largest west flowing river in India, originates from Multai (Betul district) in Madhya Pradesh (M.P.) at an elevation of 752 m having length of 724 km and falls in to the Arabian Sea at little beyond the Surat city. The total drainage area of Tapi is 65,145 km^2 out of which 9804 km^2 lies in Madhya Pradesh, 51,504 km^2 lies in Maharashtra and 3837 km^2 lies in Gujarat.

Figure 1. Map of Punagam area, Surat City.

Punagam area is a part of Surat city of Gujarat. Surat has seven zones and Punagam is located in East zone as shown in Figure 1. In 2011, Surat had population of 4,466,826 of which male and female were 2,543,145 and 1,923,681 respectively. The population of our study area, Punagam is 3, 46,598. The study area covers residential area about 600.83 Ha. When the water from the distribution network reaches to the Punagam area there is sudden decrease in the pressure head due to which water related problems arises.

Leakages, failure of pipes and other factors are there which affects the capacity of water distribution network. Therefore it is required to analyze the existing network of the Punagam area using WATERGEMS V8i and compare computed result with actual result which is obtained from Surat Municipal Corporation. The water distribution systems of Punagam are i.e. WDS-E3 network systems: - ESR-E7, ESR-E8, ESR-E9, ESR-E9A and ESR-E10.

4 WATERGEMS V8i OVERVIEW

WaterGEMS was originally developed by the Company Haestad Methods, Inc. based in Watertown, CT (USA). This company was acquired by Bentley Systems in mid-2004, acquisition from which the product began to be known commercially as Bentley WATERGEMS V8i. It is a product whose launch was in early twenty-first century and later software product, WATERCAD is the same software house that launched in the 90s. For many experts, WATERGEMS V8i is more than an evolution of WATERCAD. It is essentially a 'super (which is already included in WATERCAD), adds seamless integration with GIS environments and includes in a single commercial version all the advanced analysis modules which can only acquires separately in WATERCAD. In this sense, it is a software whose target user is the company that operates supplies, regulators and / or important consulting projects. In terms of basic and intermediate tasks, Hydraulic Modeling, WATERCAD and WaterGEMS are similar products (in fact share the same engine hydraulic calculation) and the same structure data model, so a model created in WATERCAD can be read in WATERGEMS V8i and vice versa. While WATERCAD supports an autonomous platform (Stand Alone) and Micro Station and AutoCAD (as an addition to the product). WATERGEMS V8i adds support for ArcGIS to previous environments. In recent years, the software has had a great evolution especially in features such as interoperability, ease of use, productivity tools, connection to external data, consultation processes multi-criteria, operations of spatial analysis, graphics capabilities, integration with Systems Geographic information (GIS), etc. Within the most recent developments include the following features like Data Exchange with other Information Systems, Electronic Devices and / or other management programs, Using Genetic Algorithms for automated processes hydraulic calibration, optimal design and energy optimization, Analytical Leakage Detection, Vulnerability Plans to Pollution Events, Systems integration with SCADA, Multi-parameter Quality Analysis, Network Renewal Planning, Integration with Analysis of Hydraulic Transients and Waterfall.

WATERGEMS V8i is a hydraulic modeling application for water distribution systems with advanced interoperability, geospatial model building, optimization, and asset management tools. From fire flow and constituent concentration analyses, to energy consumption and capital cost management, WATERGEMS V8i provides an easy-to-use environment for engineers to analyze, design, and optimize water distribution systems. WATERGEMS V8i is a multi-platform hydraulic and water quality modeling solution for water distribution systems with advanced interoperability, geospatial model-building, optimization, and asset management tools. From fire flow and constituent concentration analyses, to energy consumption and capital cost management, WATERGEMS V8i provides an easy-to-use environment for engineers to analyze, design, and optimize water distribution systems. WATERGEMS V8i is useful for managing the water system data, time-series hydraulic result, current and future scenarios and other core infrastructure data all within the same GIS environment. (Calvin et al., 1996).

4.1 Superior interoperability

WATERGEMS V8i users enjoy the power and versatility afforded by working across CAD, GIS, and stand-alone platforms while accessing a single, shared, project data source

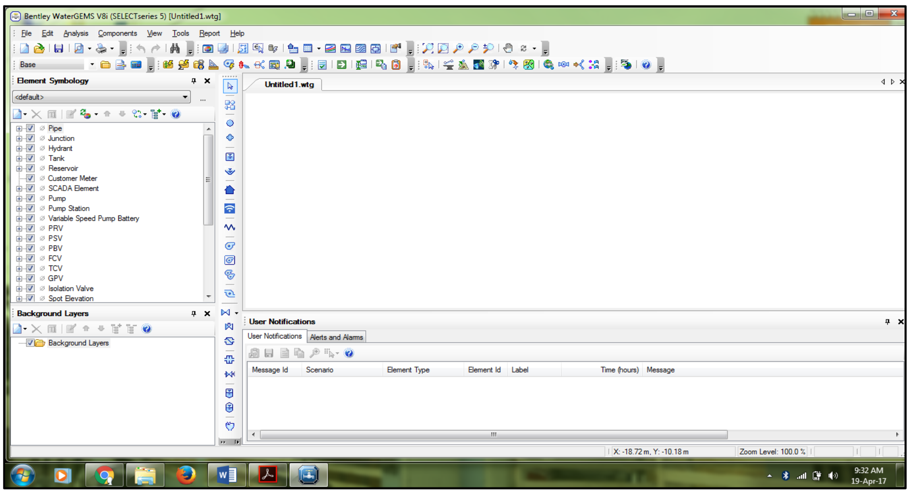

Figure 2. WATERGEMS window.

With Water GEMS, utilities and consultants can choose to model from within four interoperable platforms namely Windows stand-alone for ease of use, accessibility, and performance, ArcGIS for GIS integration, thematic mapping, and publishing, Micro-Station for bridging geospatial planning and engineering design environments, AutoCAD for CAD layout and drafting Modeling teams can leverage the skills of engineers from different departments, and engineers can flatten learning curves by choosing the environment they already know and provide results that can be visualized on multiple platforms. Figure 2 shows the WATERGEMS V8i window.

4.2 Streamlined model building

Engineers can leverage geospatial data, CAD drawings, databases, and spread sheets to jumpstart the model building process. Water GEMS provides synchronized database connections, geospatial links, and advanced model-building modules that connect with virtually any digital data format. Water GEMS includes Load Builder and TRex modules to help engineers allocate water demands and node elevations based on geospatial data found in shape files, geodata bases, various types of DEMs, and even CAD drawings. These modules help engineers avoid potential manual-input mistakes. Water GEMS also provides drawing and connectivity review tools to guarantee a hydraulically coherent model (Germanopoulos et al., 1986). Skelebrator automatically removes network complexity, while maintaining hydraulic equivalence, to efficiently tackle a wider range of modeling applications.

4.3 Optimized model calibration, design and operations

WATERGEMS includes state-of-the-art genetic algorithm optimization engines for automated calibration, design and rehabilitation, and pump operations. Darwin Calibrator evaluates millions of possible solutions to let users quickly find a calibration hypothesis that best matches measured flows, pressures, and on/off status, empowering users to make reliable decisions based on accurate hydraulic simulation of the real world. WATERGEMS SCADA Connect module lets modelers automatically acquire supervisory control and data acquisition (SCADA) data, creating a real-time system simulator that accurately represents current system conditions. It also enables WATERGEMS model results to be published to a utility's existing SCADA control room screen(s), helping to forecast operating conditions and potential issues. Darwin Designer automatically finds maximum benefit or minimum-cost designs and rehabilitation strategies, based on available budget, construction cost, and pressure and velocity constraints.

Engineers can also analyze energy consumption to identify the most energy efficient pump scheduling strategy. Darwin Scheduler optimizes the operations of fixed- and variable-speed pumps, and tank storage, to minimize energy usage or energy cost, based on pressure, velocity, pump start, and tank level constraints. Energy costs can be aggregated across pumping stations and factor in complex tariffs as well as non-model-related energy costs, to perform net present value analyses of their operating scenarios.

5 METHODOLOGY

Following are the step has been carried out to analyze existing Water Distribution Network using WATERGEMS V8i:

- Step 1: Encoding of Input Data

  Most of the hydraulic analysis software has common input data requirements. These data are grouped into pipe data and node data. Pipe data are the assigned pipe number, pipe diameter (mm), C-value, length (m) and diameter (mm). Node data are assigned node number, elevation (m) and water demand (lps). Pump curve data are the assigned head (m) and flow (lps). Figure 3 to Figure 5 shows process from starting of the program up to input data inserted in software.

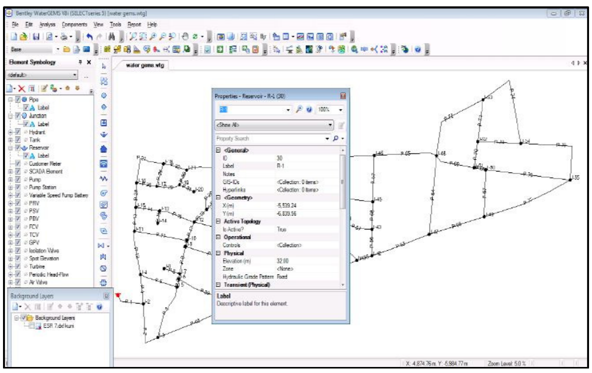

Figure 3. Layout of pipe network drawn.

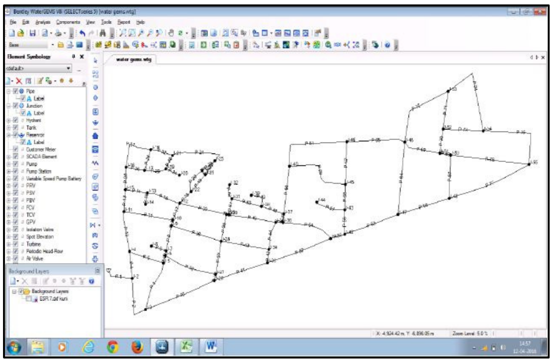

Figure 4. Property editor for reservoir

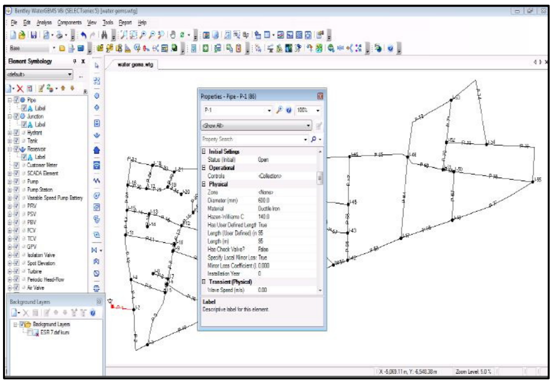

Figure 5. Property editor for pipe.

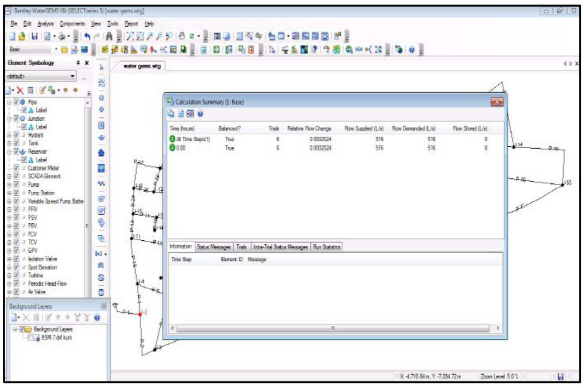

Figure 6. Simulation process in WATERGEMS.

- Step 2: Hydraulic Network Simulation

  This step is done by WATERGEMS. If all the data required have been input, the software could proceed with its hydraulic run. The software computes the head losses (m) in each pipe, the rate of head loss (m/km) in each pipe, the flow velocities (m/s), and the pressure in each node (m).
- Step 3: Examination of Hydraulic Run Results

  Usually all possible hydraulic parameters can be shown from the computer run results.
- Step 4: Finalizing the Network Configuration

  The model is subjected to repeated simulation and data adjustments until an acceptable network configuration is reached.
- Step 5: Result and Analysis

WATERGEMS generates the results in table and graph format as shown in Figure 6. Results given by software programme in form of table and graph are displayed.

6 RESULTS AND RESULT DISCUSSIONS

The network diagram of WDS ESR E10 drawn in WATERGEMS V8i is shown in Figure 7.

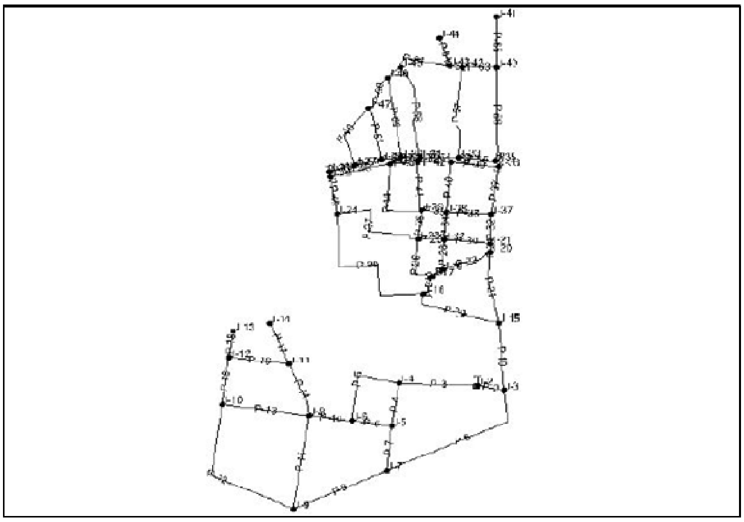

Figure 7. Network diagram of WDS ESR E-10.

After collecting data of distribution network of Punagam area pressure, flow and velocity were computed using WATERGEMS V8i and by following the methodology described outputs by WATERGEMS V8i were obtained. The error between actual pressure and pressure computed by WATERGEMS is also shown in table 1. Pressure profile for WDS ESR E10 by WATERGEMS is shown in figure 8.

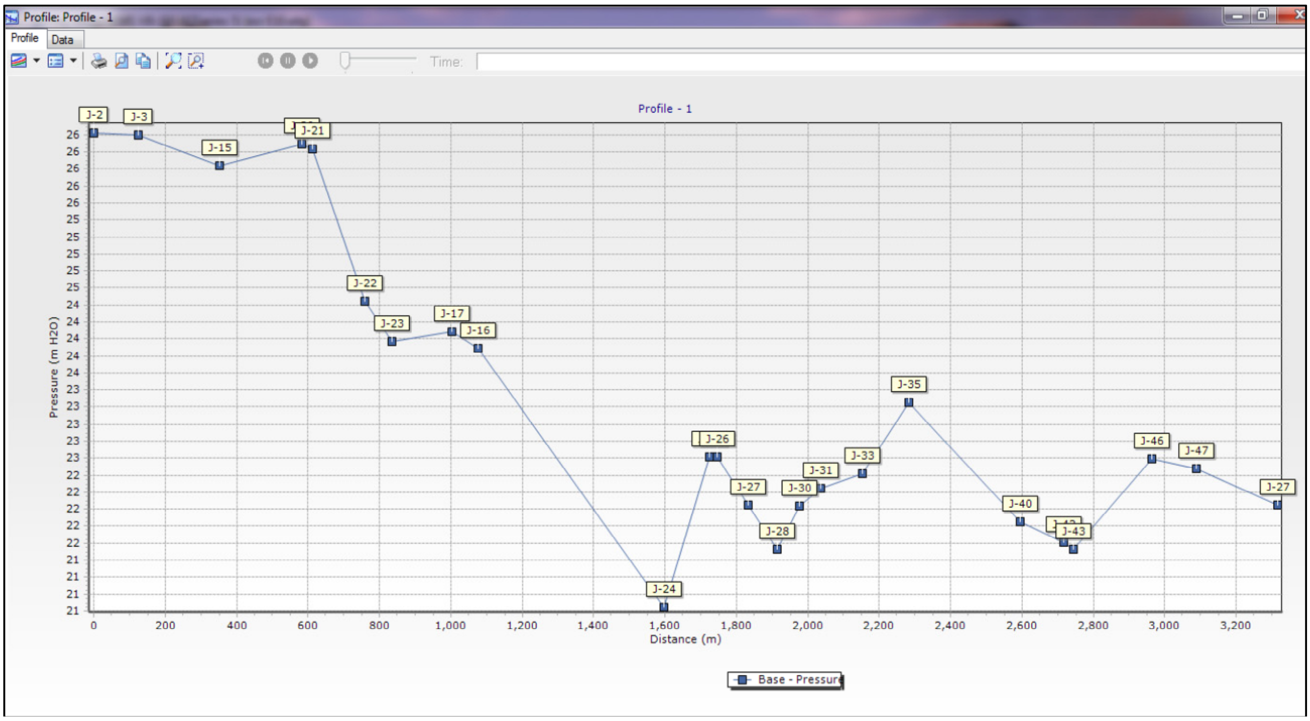

Figure 8. Pressure profile of WDS ESR E 10.

Table 1. Junction report analysis using WATERGEMS.

Label	Pressure (m)		Error (m)
	Actual	WATERGEMS	
Jn2	24	23	-1
Jn3	24	23	-1
Jn4	24	23	-1
Jn5	22	21	-1
Jn6	21	20	-1
Jn7	20	19	-1
Jn8	21	20	-1
Jn9	20	19	-1
Jn10	17	17	0
Jn11	20	19	-1
Jn12	19	18	-1
Jn13	19	19	0
Jn14	19	19	0
Jn15	24	23	-1
Jn16	21	21	0
Jn17	22	21	-1
Jn18	22	21	-1
Jn19	24	23	-1
Jn20	24	23	-1
Jn21	24	23	-1
Jn22	22	21	-1
Jn23	21	21	0
Jn24	18	18	0
Jn25	20	20	0
Jn26	20	20	0
Jn27	20	19	-1
Jn28	19	19	0
Jn29	19	19	0
Jn30	20	19	-1
Jn31	20	19	-1
Jn32	20	19	-1
Jn33	20	19	-1
Jn34	20	19	-1
Jn35	21	20	-1
Jn36	21	20	-1
Jn37	24	23	-1
Jn38	22	22	0
Jn39	21	21	0
Jn40	19	19	0
Jn41	21	20	-1
Jn42	19	19	0
Jn43	19	19	0
Jn44	20	20	0
Jn45	20	20	0
Jn46	20	20	0
Jn47	20	19	-1

Following are some finding of above study:

The total number of junctions is 47. The pressure is computed using Hazen-William approach. For WDS-ESR-E10 Jn-2, Jn-3, Jn-4, Jn-5, Jn-6, Jn-7, Jn-8, Jn-9, Jn-11, Jn-12, Jn-15, Jn-17, Jn-18, Jn-19, Jn-20, Jn-21, Jn-22, Jn-27, Jn-30, Jn-31, Jn-32, Jn-33, Jn-34, Jn-35, Jn-36, Jn-37 and Jn-41 junction gives negative pressure. As per above study there is fluctuation in the pressure head.

7 CONCLUSIONS

Based on the above study, it was found that the resulting pressures at all the junctions and the flows with their velocities at all pipes are adequate enough to provide water to the study area as per the consumer needs. There may be leakages in the pipes which results in the pressure difference which consequently results into the scarcity of water. Comparison of these results indicates that the simulated model seems to be reasonably close to actual network. With the use of this software one can indeed analyze the network at the desk and can foresee the error, if any, in the design and consequently the changes required to be done in such designs for its successful execution at site. The result reveal that the software used for the design has the capability to handle various pipe network problems without changing in model of or mathematical formulation. The software used was a viable alternative to other methods particularly in view of accuracy and its results in a simpler algorithm, without any iterative process.

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THE ROLE OF RAINWATER HARVESTING TECHNIQUES ON PREPARATION OF WATER REQUIRED FOR VEGETATION IN ARID AND SEMI-ARID REGIONS

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ABSTRACT

Water harvesting Knowledge has an ancient history. From old times, people, specially, occupants of arid lands whose access to water was limited, invent different ways to collect and conserve water. Today, many of these methods are reclaimed and introduced as Indigenous Knowledge. There are many case studies in different branches of water harvesting and new methods based on Indigenous Knowledge that have been presented. These studies especially in our country, which is situated in the desert belt, are of importance. Present study was carried out in a watershed near Mashhad in Iran. Given that Mashhad city is situated in a semi-arid zone in Khorasan Razavi, therefore, is in a good situation for this study. The selected area located in Dehbar district, south of Mashhad contains different parts with various slopes. Basic meteorology data were collected and essential soil properties were measured in soil lab. Based on references, experiences and the local characteristics, it was attempted to choose the best structures for the area. Negarim microcatchment and absorbing Banquette was chosen for both of the slopes. During the nine months, after each precipitation, soil sampling was done with six times of repeating process. Soil moisture was calculated after each time. Using basic data and soil information, Changing Procedure of soil moisture was studied. Graph analysis showed that in total, both structures performances were 20% better than the control plots. At the end of precipitation period, losing moisture in control plots is about two times more than the structures, an average of 30%. The acquired results confirm the success of tested structures on utilization of soil moisture.

Keywords: Water harvesting; arid lands; Negarim microcatchment; absorbing banquette; soil moisture.

1 INTRODUCTION

In arid and semi-arid areas, rainfall is low and unpredictable with unsuitable timing. Majority of rainfall is transformed into runoff due to several factors including lack of vegetation and high intensity. Furthermore, in these areas, evaporation is very high which would make the low level of rainfall unavailable. That is why various systems for collecting and utilization of water has been frequently used since old times (Laura, 2004). Available records in rainwater harvesting field shows that after widespread drought in Africa that caused serious damage to the crops, in 1970's and 1980's general attention focused on water harvesting which led Evenari et al. (1971) to use these methods for the first time in Palestine desert (with the average precipitation of 90mm per year) that resulted in increased food production. Boers and Ben Asher (1982), executed water harvesting systems including farming contours, surface runoff storage in underground reservoirs, construction of regional microcatchments to improve soil moisture and water storage in small turkey nest farms in the Negev Desert. Hatibu and Mahoo (1999), did a comprehensive study on the usage of water harvesting systems for the recovery of soil moisture within a field in Tanzania. de Azagra et al. (2016), studied indigenous knowledge of structures such as microcatchments, contour bunds, Bankettes and rock bunds. The purpose was to evaluate the effect of a modified model for these water harvesting structures on the hydrological regime of soil and vegetation without damaging interference in the region's ecosystem. The result of these findings ultimately led to presentation of Modipe software model. The application of this model is to estimate the most efficient structure for the land according to local conditions. In a study, Razzaghi (2011), investigated the positive impact of Meskat reclamation systems and Zey pitting holes on increasing moisture retention in the region, improving the efficiency of agricultural production and restoring the pastures in Libya. Hosseini et al. (2005), assessed and monitored soil moisture retention in the Bankettes using statistical tests, to compare them with the natural conditions in a 5-month study in Taleghan, Iran. Results showed the positive effect of Bankette structure in increasing soil moisture. Tabatabaei Yazdi et al. (2010), attempted to estimate rainwater harvesting potential using rainfed supplemental irrigation in Khorasan Province of Iran with arid and semi-arid climatic conditions, and stated about 70% increase in production outputs. Gebretsadic (2009), managed to grow native plant species with no irrigation and only using water stored in Negarim Microcatchments constructed at the project site, in a three-year time period in a case study in dry cold heights of Austria. Studies on the effects of diamond and crescent microcatchment systems on soil moisture and seedlings survival in Azadshahr region of Golestan province in Iran showed that in a 5-year period, soil moisture increased, and seedlings grown under rainfed conditions, while seedlings in observation areas did not survive, so the systems are suitable locations to store moisture and seedlings grown under rain fed conditions while seedlings in observation plot did not survive (Shahini and Roughani, 2012). Studies on diamond microcatchments on the east of Golestan province of Iran in Maravetape area showed that in semi-arid conditions in this area, rainfed Olive gardens can be created. Establishing an insolation nylon system in the collecting area of these systems, increased the runoff volume in the planting areas of olive seedlings three times more than the annual rainfall of the area (Shahini and Roughani, 2013).

Present study attempted to assess the effects of few rainwater harvesting systems on soil moisture increase and also moisture remaining time period to supply vegetation water requirement in arid and semi-arid areas near Mashhad in north east of Iran.

2 MATERIALS AND METHODS

2.1 Location of the study

Since the study was to evaluate the effect of water harvesting systems in arid and semi-arid, Khorasan Razavi province of Iran was selected as the study area, about 10 km distance from the Mashhad city, and in south of Torghabeh county, Dehbar watershed, at 59°, 22' and 27" E longitude, and 36°, 13' and 31" N latitude. This area is a part of Binalud highlands in terms of topography. Figure (1) shows a view of the related study area inside Dehbar watershed.

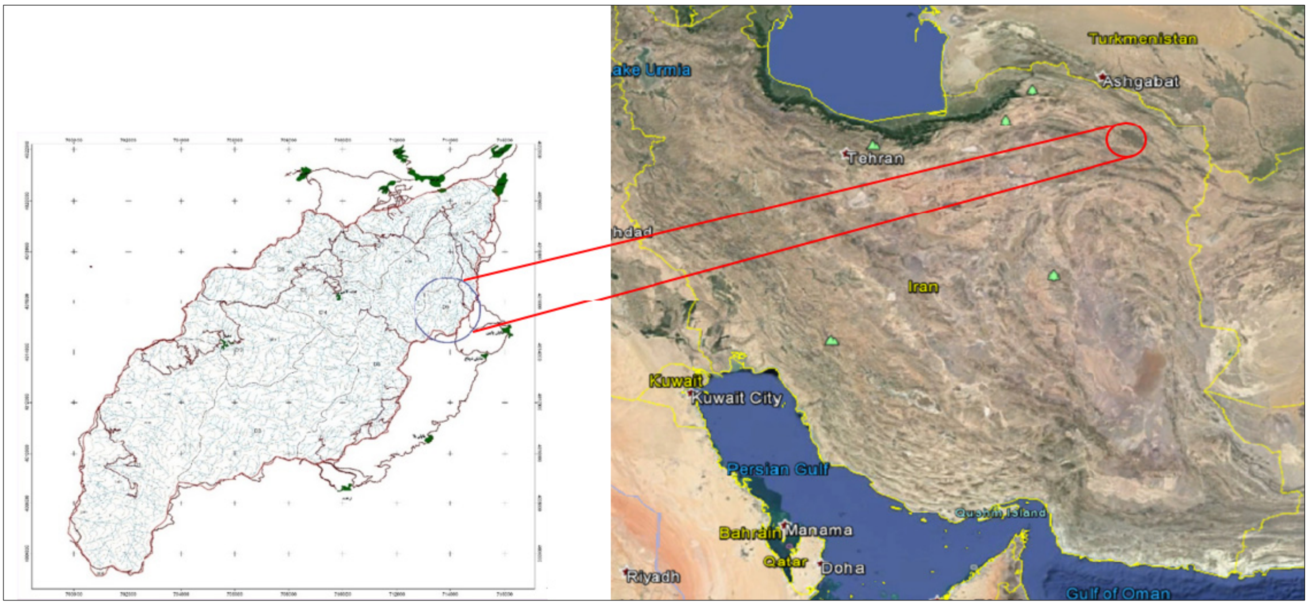

Figure 1. Study area location.

2.2 Research data and methodology

On the selected hillside of the case study, the slope of the area was measured and two places were selected for construction of the systems one in upstream part with 2.4% land slope and the other one in downstream part with 22% land slope. From geological point of view, the study area is situated in Mashhad geological sheet which is a part of Binalud structural zone, containing gray to black Teriassic aged Mashhad slits and Filits in rotation with Shale, sandstone and Jurassic Conglomerate. Important characteristics of soil including texture, pH, EC, lime percent, porosity, organic materials, bulk density and true density were measured in the lab for both catchment areas and infiltration pits of the structures in two depths of (0-15) and (15-30) cm. The results of these assessment showed that based on pH, regional soils are in the category of low alkaline soils. Also, the salinity is in low level, and texture is loam and clay loam in all collected soil samples. Soil lime percentage and organic materials are low as well. In terms of porosity, bulk density and true density, the soils are classified in agricultural average condition. To collect precipitation data, rain gauge graphs of Mashhad synoptic meteorological station were used. By extracting information from these graphs and unite conversion, the amount, intensity and duration of precipitation events were calculated for the nine-month study duration.

According to initial investigation for constructing the structures, it was decided that each structure had to be built in both slopes with an observation (control) area for each one. Selected sides for each microcatchment was 3.33 meters resulting in about 10m^2 of runoff collecting area. The area of infiltration pits was selected to be 1m^2, so the rate of catchment area to cultivated area is about 10. Infiltration pits were situated in the lowest part of each microcatchment to ease the runoff flow from all parts of the catchment.

Figures 2 and 3 show the constructed microcatchments in this research. Each microcatchment contains two parts: catchments area which provides the runoff, and the cultivated area which receives the runoff collected in catchment area.

Figure 2. A view of the constructed Bankette structure.

Figure 3. A view of the constructed Negarim Microcatchment.

To study the soil moisture process, after each precipitation, from all the runoff collecting areas and also infiltration pits in both slopes (2.4% and 22%) and in two depth (0-15 and 15-30cm) soil samples were collected and the moisture content was measured. For each precipitation event, sampling had 5 repetitions (with three days' time intervals). Therefore, in every sampling round, 20 samples were collected and transferred to the lab. To review and assess the soil's hydrological condition and completing the needed data for evaluation, Curve Number (CN) had to be calculated. Due to the results of soil texture, soil hydrological group was estimated as group C. In field visits, pasture lands hydrological condition was estimated as poor with less than 50% vegetation cover. Also, precedence soil moisture status was calculated using the results of precipitation monitoring. Using these information, curve numbers were calculated as shown in table (1).

Table 1. Rainfall events and curve number calculation.

Sampling date	Cumulative precipitation of last 5 days	Total precipitation	Precedence moisture condition	Curve Number
2014.10.14	1.6+5.0+0+0+1.3	7.9	1	72
2014.11.6	3.1+7.7+7.1+1.0+8.7	6.18	2	86
2014.11.26	0+0+0+2.6+9.2	1.9	2	86
2014.12.24	1.1+0+9.3+2.40	2.9	2	86
2015.1.11	2.2+2.8+9.20+0	14	2	86
2015.2.16	5.0+5.15+0+2.1+6.2	8.19	2	86
2015.2.19	9.4+9.0+0+5.0+5.15	8.21	3	94
2015.2.22	3.1+10+3+9.4+9.0	1.20	3	94
2015.3.7	1.0+3.10+5.1+0+1.1	13	3	94
2015.3.10	3.10+1.0+7+0+0	4.17	3	94
2015.3.27	6.6+7+0+0+4.0	7.7	3	94
2015.3.31	6.6+7+0+0+0	6.13	3	94
2015.4.5	0+0+0+3.2+2.3	5.5	3	94
2015.5.8	0+0+3.4+1.1+9.12	3.18	2	86

3 RESULTS AND DISCUSSIONS

3.1 Calculation of runoff and infiltration

For each structure in each rainfall, the amount of runoff and infiltration was calculated. According to table (2), result of these assessments showed that in the first month of sampling, about half of the occurred precipitation forms the total runoff and infiltration and the other half has been lost from the area in different shapes of waste especially evapotranspiration. Due to low precipitation amount and intensity and high potential of evapotranspiration, soil moisture in the first three months of sampling was very low. The increase in the rainfall events in winter months and its continuity affects the infiltration and runoff percentage positively. The aim of monitoring the rates of runoff and infiltration is to analyze soil moisture changing procedure during the sampling time period.

Table 2. The calculation of runoff and infiltration in structures.

Sampling dates	Negarim Upstream catchment		Bankette Upstream catchment		Negarim Downstream catchment		Bankette Downstream catchment		Total
	Q(mm)	W(mm)	Q(mm)	W(mm)	Q(mm)	W(mm)	Q(mm)	W(mm)	Q+W
2014.10.14	1.2	0.56	0.95	0.6	1.05	0.58	1.1	0.57	6.61
2014.11.6	0.7	0.66	1.5	0.63	1.2	0.64	1.2	0.64	7.17
2014.11.26	0.8	0.92	0.8	0.92	0.7	0.93	0.7	0.93	6.7
2014.12.24	1.2	0.44	1.2	0.44	2.4	0.4	2.4	0.4	8.88
2015.1.11	2.5	0.76	2.6	0.76	2.7	0.75	2.7	0.75	13.52
2015.2.16	2.9	0.68	3	0.62	3.1	0.62	3	0.62	14.54
2015.2.19	0.28	0.79	3	0.67	3.2	0.68	2.8	0.7	12.12
2015.2.22	3.1	0.51	3	0.52	3.2	0.51	3.1	0.51	14.45
2015.3.7	2.7	0.54	2.7	0.54	2.8	0.53	2.8	0.53	13.14
2015.3.10	2.9	0.53	3	0.53	3.2	0.52	3.2	0.52	14.4
2015.3.27	2.7	0.41	2.7	0.41	0.27	0.62	0.27	0.62	8
2015.3.31	2.9	0.89	3.2	0.86	0.36	1.1	3.3	0.86	13.47
2015.4.5	0.27	0.47	0.27	0.47	1.1	0.4	1.1	0.4	4.48
2015.5.8	2.5	1.32	2.6	1.31	2.8	1.3	2.8	1.3	15.93

3.2 The effect of the proposed structures on the soil moisture process

To investigate the usefulness of implemented techniques in the soil moisture, sampling occurred regularly after each rainfall event with five repetitions every three days to calculate bulk and volumetric moisture. Using these data provided the possibility to evaluate and compare of changes in soil moisture volume during a crop year in study and the related observation areas. According to figures (4) and (5), this study showed that there is an average of 25% difference in moisture retention, between Negarim Microcatchment infiltration pits and the related observation area for the of 2.4% slope site. This difference reaches 30% in the 22% slope site. There were no meaningful differences between the moisture content of (0-15) and (15-30) depths. Also, the difference in moisture content between Absorbing bankette infiltration pit and the related observation area in 2.4% and 22 % slope sites were respectively 27% and 31 %. There were no meaningful differences between the depths here either. Study shows that in the beginning of sampling in Autumn, where amount, intensity and duration of the rainfall events were relatively low and the soil was dry (due to hot summer with no rainfall), moisture change process is mild. The increase in rainfall intensity, duration and occurrences in February and March made a stable moisture period in infiltration pits which followed by 30% increase in soil moisture of both structures while moisture increase in observation areas were only about 15 % in average. These results show an agreement with those reported by the case studies of de Azagra et al. (2004), de Azagra (2008), Hosseini et al. (2005), Gebretsadic (2009), Razzaghi (2011), Shahini and Roghani (2012; 2013), Sadeghzadeh Reyhan et al. (2013) and Rehman et al. (2014). Also, in all of these studies, the common method for determining soil moisture were TDR or bulk moisture measurement like this study.

Moisture process comparison between bankette catchment area and infiltration pit in two slopes and (0-15) depth

Moisture process comparison between bankette catchment area and infiltration pit in two slopes and (15-30) depth

Moisture process comparison between Negarim catchment area and infiltration pit in two slopes and (0-15) depth

Moisture process comparison between Negarim catchment area and infiltration pit in two slopes and (15-30) depth

Figure 4. Moisture content comparison between catchment and infiltration areas of both structure.

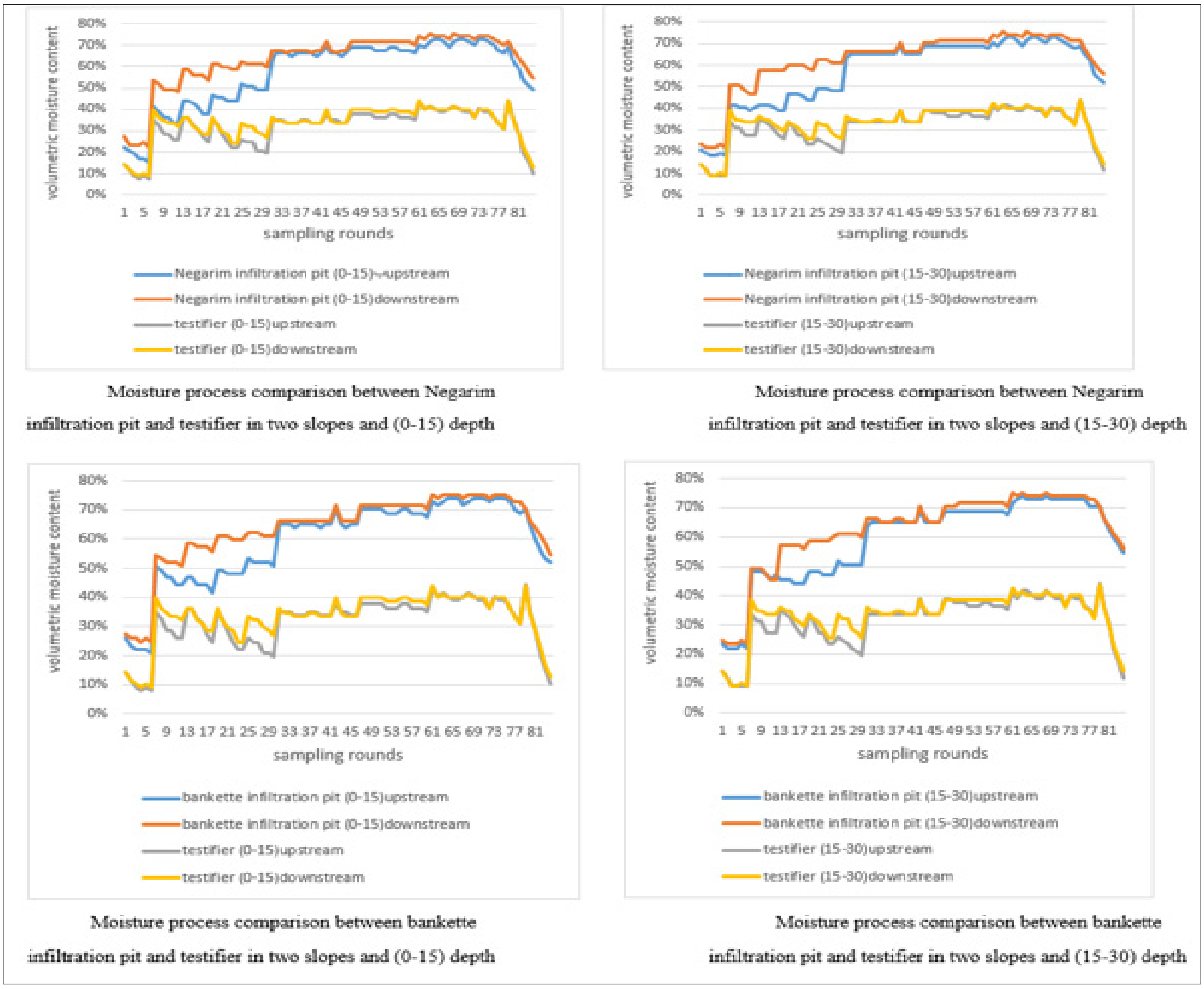

Figure 5. Moisture content comparison of infiltration pits of both structures with the related observation plot in both slopes.

To verify the effect of structures on runoff harvesting, two statistical hypothesis tests (0 and 1 tests) were used. In the first test, zero hypothesis (H0), absence of significant difference in moisture between infiltration pits and observation area and in one hypothesis (H1), existence of significant difference in moisture between infiltration pits and observation area was considered.

According to the results, there is no difference between moisture average of catchments areas and the related observation areas in significant level of 1% and 5% in both structures with same slope and depth. Therefore, it can be safely said that there is a harmony between catchments and the related observation areas. Test results between infiltration pits of both structures and the related observation areas show significant difference in moisture average in significant level of 1% and 5% in both depths and slopes, which means that the differences in moisture retention between infiltration pits and the observation areas are impressive and the structures functions are successful. Studies of Hosseini et al. (2005), Razzaghi et al. (2011), Shahini and Roghani (2012; 2013), Sadeghzadeh Reyhan et al. (2013) and Rehman et al. (2014) who used hypothesis tests to prove the significance of their results, also found the same results.

4 CONCLUSIONS

In overall, the performance of both structures used in this research is much better than the observation areas. In 2.4% slope area, absorbing Bankette was better than the Negarim microcatchment by the average of 2%. This difference in 22% slope area is only 1%. Sampling depth did not have a significant effect on the results. Also, the average performance of both structures in comparison to the observation areas is about 10% higher. This difference reaches 30% in winter rainfall events. In the last few rainfalls, moisture decrease process in structures is about 10% in average, while the observation areas lost about 30% of soil moisture during the same time period. By examining the performance of the structures, it can be said that using water harvesting methods, is a non-aggressive approach in the recovery of soil moisture in local scale, which has an impressive effect on soil moisture storage especially in short time periods with relatively low expenses. Using these methods on longer periods of time (more than two years) can also help the vegetation recovery and soil fertility. Also, this study proves the success of both of the structures which were provided and tested. Using similar methods and promoting them as native case studies would help the development of scientific resources and information in water harvesting and management. Using this case study especially for longer periods of time can also improve soil fertility and green coverage in addition to soil moisture increase as well as aquifer recharge, which would present a chance to improve the water and agricultural condition on arid and semi-arid regions.

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WATER SUPPLY MANAGEMENT IN SMALL CITY DURING DRY SEASON

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ABSTRACT

In Indonesian province of East Java Province, there are some areas have not enough fresh water discharge during dry season. Among them are Trenggalek, Ponorogo, and Pacitan cities. Almost every year drought occurs in these three cities. Consequently, it is necessary to intercept and retain falling water during raining season with appropriate retardation basin. In this paper, the water balance between water demand and water supply is discussed. To increase the total discharge of water supply, retardation basin is used as an alternative to equipping water. The goal of services is only 60%, it means that not all or 100% of water demand will be supported. Only water for daily activity in each house hold will be taken as a consideration in this research. The water balance concept is used to analyze the balancing of water demand and availability of water supply. In principle, the materials used in this research are topographic map in scale of 1:25.000, SPOT satellite remote sensing data, land use map, discharge of river, spring, lake, and others water storage. The total discharge of water supply is analyzed using water discharge from potential water resources surrounding the research area. Base on the balancing of total water demand and total water supply, the lack between water demand and water supply can be found. The lack of water supply should be fulfilled using new water supply system. From the analyzed result, it can be concluded that Pacitan city have water supply surplus is equal to 27.39 l/sec. Ponorogo and Trenggalek cities has lack of water supply which are 26.48 l/sec. and 50.31 l/sec, respectively. Consequently, it is necessary to fulfill the lack of water supply by employing the water resources available surrounding two cities. The surplus of water supply from Pacitan city is not enough discharge to cover the water lack in two others cities.

Keywords: Water balance; water demand; spring water; retardation basin.

1 INTRODUCTION

Water is one of most important factor for human life. It is known that no human can live without water. There are many water sources on planet earth. The total volume of water in the world is 1.4 billion km^3 (Chow, 1988). Among them, 97.5% is sea water while only 2.5% is fresh water, which is can be used directly for human life. It means it is very limited volume of fresh water which is available to support for human life and the activities. Almost all the fresh water comes from rain. Consequently, if an area receives a lot of rain, there are a lot of fresh water which can be used for human activities. Such as in Indonesia, there are only two seasons, rain and dry season. Of course, during raining season, there is enough discharge of fresh water to support human activities. On the other hand, during dry season some areas do not have enough fresh water discharge to meet the water demand. Moreover, drought seldom occurs in an area.

In East Java Province Indonesia, there are some areas that do not have enough fresh water discharge during the dry season. Among them are Trenggalek, Ponorogo, and Pacitan cities. Almost every year, drought occurs in these three cities. Consequently, it is necessary to intercept and retain falling water during the raining season with appropriate hydraulic structures such as small dam, long storage, and others retardation basin. In this paper, the number and volume of hydraulic structures that need to support water demand is discussed. The goal of services in this work is only 60%, which means not all or 100% of water demand will be supported. Only water for daily activities in households will be taken as a consideration in this research. In this research, the water balance concept is used to analyze the balancing of water demand and availability of water supply.

2 RESEARCH AREA

This research was done in East Java Province, Indonesia. Inside of East Java Province area, there are three cities which were used as samples in this research. These cities are Trenggalek, Ponorogo, and Pacitan. The research data were collected through the relating agencies and field surveys (Suharyanto et al., 2015). The location of the research area is shown in Figure 1. During the raining seasons, the water demand in these cities can be fully supplied from the surface water. The source of surface water are coming from detention pond, small dam, and others reservoirs. On the other hand, in the dry season the water that was collected in the detention is not enough to supply the water demand throughout the season. Normally, the raining season starts in October and finishes in March. The dry season starts in April and finishes in September. Therefore,

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the water that was collected during the raining season is not enough to supply the water demand for 6 months during dry season. Usually, in the beginning of fourth month the reserved water in all detention pond is empty. Only water in one lake, located in Ponorogo city still have enough discharge. The lake, namely Ngebel and is located about 20 km from Ponorogo city center. From this situation, it is necessary to find the solution how to fulfill enough water demand during dry season, especially from fourth month of dry season in the three cities. Efforts such as increasing the number of detention ponds, transborder water supply between three cities, and effecting water use from Ngebel Lake were proposed.

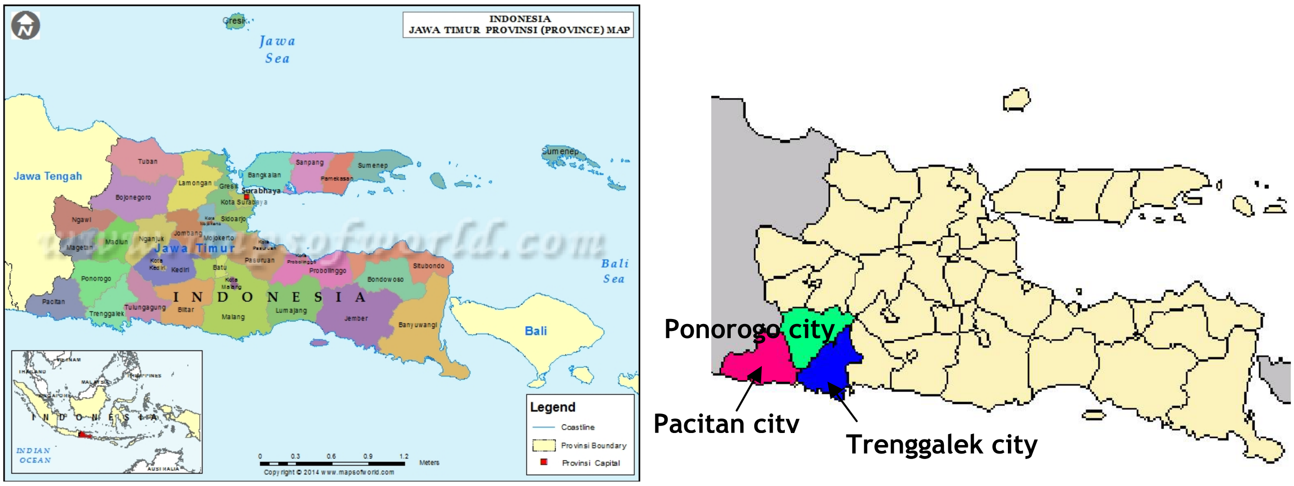

Figure 1. Location of research area.

3 MATERIALS AND METHODS

In principle, the materials used in this research are topographic map in scale of 1:25.000, SPOT satellite remote sensing data, land use map, discharge of river, spring, lake, and other water storages. To calculate the water demand, the standard water demand for daily live as shown in Table 1 is used (SNI, 2002). The domestic water demand is computed using Eq. [1]. The total discharge of water supply was analyzed using water discharge from potential water resources surrounding in the research area (Diaz, 2009). Base on the balancing of total water demand and total water supply, the lack between water demand and water supply can be found. The lack of water supply should be fulfilled using new water supply system. In order to make water quality ready to be used as fresh water, the water purification system also need to develop.

To predict the water demand discharge, it is necessary to know the population density in the research area. Eq. [2] and [3] are used to predict the growing of population density 10 years into the future. The water demand is analyzed based on the water demand for daily activity (domestic water demand), livestock, fishery and agriculture (Suharyanto, 2015). The water demand for livestock, fishery, and agriculture area were analyzed using Eq. [4], [5], [6], and [7], respectively.

Table 1. Standard domestic water demand.

	Categories	Population	Level of water demand
1	Metropolis	> 1,000,000	120 l//person/day
2	Big city	1,000,000	100 l/person/day
3	Medium city	500,000	90 l/person/day
4	Small city	100,000	60 l/person/day
5	District city	< 20,000	45 l/person/day

$$Dom = Pn \times Wn \qquad [1]$$

where:
Dom = Domestic water demand
Pn = Population number
Wn = Level of water demand

The water demand for non-domestic (Non Dom) were estimated using next directive (SNI, 2002).

1. Public facilities= 15% x Dom
2. Office area = 15% x Dom
3. Commercial area= 20% x Dom
4. Industrial area= 10% x Dom
5. Water demand for livestock, fishpond, and for agriculture.

The other water demand should be considered in the water demand analysis are water demand for hydrant and water lose during water supply process. The water demand for hydrant and water supply lose are:

1. Hydrant = 10% x (Dom + Non Dom)
2. Water supply lose= 10% x (Dom + Non Dom)

Population estimation using Arithmetic method is:

Pn = Po (1+rn) [2]

where:
Pn = Population in the n year
Po = Population in the base year
r = Population growth per year (%)
n = Number of projected year

Population estimation using Geometric method is:

Pn = Po (1+r) n [3]

Q(Ls) = 365 x {q(c/b) x P(c/b) + q(s/g) x P(s/g) + q(pi) x P(pi) + q(po) x P(po)} [4]

where:
Q(Ls) = Water demand for livestock (m^3/year)
q(c/b) = Water demand for cow, water buffalo, etc (l/tail/day)
q(s/g) = Water demand for goat, sheep, etc (l/tail/day)
q(pi) = Water demand for pig, etc (l/tail/day)
q(po) = Water demand for bird, fowl, etc (l/tail/day)
P(c/b) = Number of cow, water buffalo, etc.
P(s/g) = Number of goat, sheep, etc.
P(pi) = Number of pig, etc.
P(po) = Number of bird, fowl, etc.

The water demand for each livestock type was estimated using value as shown in Table 2 (SNI, 2002).

Table 2. Water demand for livestock.

	Livestock	Level of Water Demand
1	Cows, Water Buffalo, etc	40 l/tail/day
2	Goat, Sheep, etc	5 l/tail/day
3	Pig, etc	6 l/tail/day
4	Bird, Fowl, etc	0.6 l/tail/day

Q (Fs) = Aw x I_f x a_f [5]
Q (Fs) = Fresh water demand for fishpond (l/sec./ha.)
Aw = Area of fishpond (ha.)
I_f = Fish pond harvesting intensity each year
a_f = Water used standard (l/sec./ha.)
= 0,0050 m/sec/ha. x 3600 sec./hour x 24 hour/day x 150 days/season
= 0,0039 m/sec/ha. x 3600 sec./hour x 24 hour/day x 150 days/season
= 0,0008 m/sec/ha. x 3600 sec./hour x 24 hour/day x150 days/season

Q(Fp) = 365 x (g(t)/1000) x q(f) x A(Fp) x 1000 [6]

where:
Q(Fp) = Water demand for fishpond (m^3/year)
q(f) = Water demand for flashy (7 mm/year)
A(Fp) = Area of fishpond (ha)

The water demand for each fishpond type was estimated using value as shown in Table 3 (SNI, 2002).

Q(Agr) = L x I t x a [7]

Table 3. Water demand for fishpond.

	Type of fishpond	Level of water demand
1	Simple fishpond	0.8 l/sec./ha.
2	Semi intensive fishpond	3.9 l/sec./ha.
3	Intensive fishpond	5.9 l/sec./ha.

where:
A = Water demand for irrigation
L = Area of agriculture field (ha.)
I t = Crop intensity
a = Water demand standard (1 l/sec./ha.)

Finally, the total water demand was analyzed using the total of water demand from each sector such as water demand from domestic, livestock, fishpond, and agriculture. This simple equation shown in Eq. [8].

Twn = Dom + Non Dom + Hydrant + Water lose [8]

where:
Twn = Total water demand, Non Dom= Total non-domestic water demand

Due to the equations used in this research, it is necessary to prepare the land used data, number of each category of livestock, area of fish pond, number of population, number of hydrants, and water lose in the supply process. The area of land used data was calculated from land used map. The land use map was generated from SPOT HRV data using unsupervised method (Ramesh and Ayse, 2009). From this map, the area of agriculture field, fishpond, and others relating data is measured. The number of population data was found from statistical center bureau (BPS, 2014). The data relating with the fishpond was collected from Fisheries agency. For water supply data such as surface runoff, spring water discharge, and others water resources data were collected from Water resources agency.

4 RESULTS AND DISCUSSIONS

After collecting the data needed, the analysis was done using the relating formulas as described above. The analysis was done for each regency in the study area. The collected data was sorted based on 2006 until 2015. The population data was predicted to be 2025. The arithmetic formula was used to predict the future population data. The collected and predicted population data is shown in Table 4. By the same method, the population of livestock was collected. The livestock data was classified into three groups i.e. big livestock, small livestock, and fowl categories. The big livestock includes cows, water buffalo, horse, etc. The small livestock includes got, sheep, pig, etc. For fowl includes bird, chicken, duck, etc. The livestock data were shown in Table 5, 6, and 7, respectively.

Table 4. The number of population data.

	Regencies	Years					
		2006	2008	2010	2012	2015	2025
1.	Pacitan	64,325	65,135	67,999	69,127	72,240	81,795
2.	Ponorogo	76,752	78,742	79,140	87,009	93,774	117,391
3.	Trenggalek	66,333	69,969	70,943	72,915	88,074	128,503

Table 5. Big livestock data in research area.

	Regencies	Years				
		2006	2008	2010	2012	2015
1.	Pacitan	8,430	10,433	10,811	11,240	11,833
2.	Ponorogo	12,996	13,078	13,700	13,870	14,054
3.	Trenggalek	6,648	6,947	7,234	7,590	8,584

Table 6. Small livestock data in research area.

	Regencies	Years				
		2006	2008	2010	2012	2015
1.	Pacitan	13,619	14,573	14,987	14,720	14,914
2.	Ponorogo	9,012	9,576	16,142	17,918	18,714
3.	Trenggalek	23,041	23,761	24,603	23,539	25,520

Table 7. Fowl data in research area.

	Regencies	Years				
		2006	2008	2010	2012	2015
1.	Pacitan	91,189	218,616	96,169	105,846	97,753
2.	Ponorogo	79,656	79,170	156,319	184,756	181,552
3.	Trenggalek	161,102	175,525	170,818	178,258	197,125

The other data need to analyze the water demand is number of ponds. The number and area of fishpond data was collected from Fisheries agency in the research area. The collected data of fishpond area was checked using natural color composite image that was developed from SPOT HRV data. By combining band 2 as red, band 1 as green, and band 3 as blue the natural color, composite image was developed (Savary et al., 2009). By digital interpreting method (Suharyanto et al., 2013), the area of fishpond in the research area was estimated. From analyzed result the agreement of fishpond area collected from Fisheries agency and area estimated from SPOT image can be confirmed. The fishpond area data used in this research is shown in Table 8.

Table 8. Fishpond area in the research location (Ha.).

	Regencies	Years				
		2006	2008	2010	2012	2015
1.	Pacitan	4.25	6.73	5.89	6.54	6.22
2.	Ponorogo	3.15	3.89	3.01	3.35	4.55
3.	Trenggalek	2.45	3.15	2,25	2.04	2.02

The last data needed in this research is the agriculture area. This data was collected from Agriculture agency. The collected data was checked using landcover image which was generated from SPOT HRV satellite remote sensing data. The landcover image was developed using supervised method (Katpatal et al., 2008). The maximum likelihood distance was used in the classification process. The image was classified into six landcover categories. Among them is agricultural category. The area of agricultural category was estimated using the developed landcover image. The agriculture area collected from Agriculture agency was compared with the agriculture area estimated from landcover generated from SPOT HRV data. The agreement can be found from this comparison. Finally, the agriculture area used in this research is shown in Table 9.

Table 9. Agriculture are in the research location (Ha.).

	Regencies	Years				
		2006	2008	2010	2012	2015
1.	Pacitan	152.50	137.30	158.90	722,400	172.25
2.	Ponorogo	175.15	175.91	175.01	174.35	174.55
3.	Trenggalek	250.45	200.15	250,25	250.04	255.02

After all the data need in the research was collected, the analysis of water demand was done. The domestic water demand and non-domestic water demand were analyzed using the related formulas as described in chapter 3. The domestic water demand was analyzed based on Table 1 and using Eq. [1]. From analyzed result, the water demand for three agencies in the research can be shown in Table 10.

Table 10. House hold domestic water demand (liter/day).

	Regencies	Years					
		2006	2008	2010	2012	2015	2025
1.	Pacitan	6,432,500	6,513,500	6,788,900	6,912,700	7,224,000	8,179,500
2.	Ponorogo	7,675,200	7,874,200	7,914,000	8,700,887	9,377,376	11,739,099
3.	Trenggalek	6,633,300	6,996,950	7,094,300	7,291,500	8,807,418	12,850,263

The water demand for non-domestic water were calculated based on Tables 2 and 3 and using Eq. [5] to [7]. The data needed for this analysis are shown in Tables 5 to 9. The analyzed result for each regency are shown in Table 11, Table 12, and Table 13, respectively. From those tables, it can be seen that the highest demand of water demand is for agriculture area. It is realistic, because for one year the farmer have to plant the land for a minimum of two times. The biggest water demand in the agriculture area is during dry season. There are two kinds of domestic water i.e. water demand in household as shown in Table 10 and water demand for public facilities, commercial area, industrial area, and water lose as shown in Tables 11 to 13. The domestic water as shown in Tables 11 to 13 is called as domestic water 2.

Table 11. Non-domestic water demand for Pacitan regency (liter/day).

Items	2006	2008	2010	2012	2015
1. Public facilities	977,025	978,678	1,018,335	1,052,714	1,083,600
2. Commercial area	1,302,700	1,318,225	1,357,780	1,406,765	1,444,800
3. Industrial area	651,350	667,125	678,890	705,578	722,400
4. Water lose	651,350	667,125	678,890	705,578	722,400
Domestic water 2	3,582,425	3,631,153	3,733,895	3,870,635	3,973,200
5. Big Livestock	233,280	250,560	345,600	380,160	311,040
6. Small Livestock	65,837	73,786	71,971	70,848	72,490
7. Fowl Livestock	54,432	131,328	57,888	63,936	58,752
8. Fishpond	786,240	1,252,800	1,149,120	1,235,520	1,321,920
9. Agriculture area	7,845,120	6,998,400	8,121,600	8,506,080	8,894,880
Non-Domestic water	8,984,909	8,706,874	9,746,179	10,256,544	10,659,082
Total water demand	12,567,334	12,338,027	13,480,074	14,127,179	14,632,282

Table 12. Non-domestic water demand for Ponorogo regency (liter/day).

Items	2006	2008	2010	2012	2015
1. Public facilities	1,151,280	1,181,130	1,187,100	1,305,133	1,406,606
2. Commercial area	1,535,040	1,574,840	1,582,800	1,740,177	1,875,475
3. Industrial area	767,520	787,420	791,400	870,089	937,738
4. Water lose	767,520	787,420	791,400	870,089	937,738
Domestic water 2	4,221,360	4,330,810	4,352,700	4,785,488	5,157,557
5. Big Livestock	252,288	264,384	367,200	347,328	348,192
6. Small Livestock	45,014	49,248	82,080	89,424	91,325
7. Fowl Livestock	47,520	47,520	94,176	110,592	108,864
8. Fishpond	950,400	1,045,440	1,019,520	1,036,800	1,054,080
9. Agriculture area	155,1990,880	155,990,880	155,818,080	155,714,400	156,427,200
Non-Domestic water	157,286,102	157,397,472	157,381,056	157,298,544	158,029,661
Total water demand	161,507,462	161,728,282	161,733,756	162,084,032	163,187,218

Table 13. Non-domestic water demand for Trenggalek regency (liter/day).

Items	2006	2008	2010	2012	2015
1. Public facilities	994,995	1,049,542	1,064,145	1,093,725	1,321,113
2. Commercial area	1,326,660	1,399,390	1,418,860	1,458,300	1,761,484
3. Industrial area	663,330	699,695	709,430	729,150	880,742
4. Water lose	663,330	699,695	709,430	729,150	880,742
Domestic water 2	3,648,315	3,848,322	3,901,865	4,010,325	4,844,081
5. Big Livestock	150,336	152,064	192,672	196,992	138,240
6. Small Livestock	116,986	116,381	121,824	119,232	127,267
7. Fowl Livestock	96,768	105,408	102,816	107,136	118,368
8. Fishpond	501,120	561,600	475,200	423,360	371,520
9. Agriculture area	27,328,320	24,494,400	26,334,720	26,477,280	28,568,160
Non-Domestic water	28,193,530	25,429,853	27,227,232	27,324,000	29,323,555
Total water demand	31,841,845	29,278,175	31,129,097	31,334,325	34,167,636

Therefore, the total domestic water demand is sum of house hold domestic water and domestic water 2. From analyzed result, it can be concluded that the total domestic water demand in 2015 are 11,197,200 l/day, 14,534,933 l/day, and 13,651,499 l/day for Pacitan, Ponorogo, and Trenggalek cities as shown in Table 14. To fulfill this water demand, the potential water supply in the research area was investigated. The sources of water to fulfill the water demand can be drawn from surface water, spring water, and underground water. The surface water can be from river, lake, reservoir, and others. For spring water, normally water rises from land and may came from subsurface or aquifer water. In case of Pacitan city, most of water demand is supplied from spring water. The potential of surface water is very low in this area. On the other hand, Ponorogo city, most of water demand is supplied from surface water. The surface water is flowing from Ngebel Lake. The potential surface water from river in Ponorogo city is very low. The second water resources common used in Ponorogo city is water from detention ponds. The last of research area is Trenggalek city. In this area, the spring water is used as main resource for water supply. The potential surface water from river is very low.

To know the water balance between water demand and water supply discharges, it is necessary to analyze the total discharge of water resources in each research area. The total discharge of water resource can be supplied to fulfill the water demand for each research area can be shown in Table 15. By comparing the water demand as shown in Table 14 and water resource discharge as shown in Table 15, the water balance is negative. The negative water balance means the water demand is higher than water supply.

Table 14. Total water demand in 2015.

	Regencies	Types of water demand (l/day)			Total
		House hold	Domestic water 2	Non-Domestic	
1.	Pacitan	7,224,000	3,973,200	10,659,082	21,858,282
2.	Ponorogo	9,377,376	5,157,557	158,029,661	172,564,594
3.	Trenggalek	8,807,418	4,844,081	29,323,555	42,975,054

Table 15. The availability water discharge (liter/sec.).

	Regencies	2006		2015	
		Availability	Target	Availability	Target
1.	Pacitan	17.43	70.11	97.50	77.60
2.	Ponorogo	56.28	84.76	56.28	100.94
3.	Trenggalek	25,15	75,31	25,15	94,80

Therefore, it is necessary to find the new potential water resources to fulfill the negative of water balance. For Pacitan city, the total water balance for domestic water in 2006 is negative 52, 68 liter/sec. This water balance assumes that 60% of population is served and the water demand is 70.11 l/sec. The available water supply is 17.43 l/sec. The domestic and non-domestic water demand for Pacitan city in 2015 is 129.69 l/sec. If the served target is 60%, the domestic and non-domestic water demand becomes 77.76 l/sec. Therefore, the water balance is negative 60.33 l/sec. To fulfill the lack of water supply, the new water resources needs to be created with minimum discharge is 60.33 l/sec. By analyzing the potential water resources surrounding Pacitan city, the 97.5 l/sec discharge can be found. The specification of these water resources is shown in Table 16. Finally, the water balance in 2015 is positive 37.17 l/sec. The new supplied water resource mainly is coming from Sumber Barong spring water. To increase the water quantity withdrawn from Sumber Barong spring water, the water treatment installation was developed as shown in Figure 2. The condition of Sumber Barong spring water is shown in Figure 3.

Table 16. Spring water resource in Pacitan city.

	Name of Spring	Discharge (l/sec)		Name of Spring	Discharge (l/sec)
1.	Slare	8	5.	Sumber Bule	150
2.	Surupan	7	6.	Sumber Barong	400
3.	Sumber Maron	70	7.	Kali Kepuh	31
4.	Dung Wil	25	8.	Dung Timo 1	70

Figure 2. Water treatment installation.

Figure 3. Sumber Barong spring.

Ponorogo city condition is different with Pacitan city condition. The domestic water demand in 2008 on Ponorogo city is 84.76 l/sec. The available water discharge is 58.28 l/sec. Therefore, the water balance is negative 28.48 l/sec. On 2015, the domestic water demand it was increased and became 100.94 l/sec. The lack of water balance also increased became 44.66 l/sec. Consequently, the new water resources are necessary to fulfill the lack of water balance. The lack of water balance is fulfilled using the discharge from several spring and lake surrounding the Ponorogo city. From the analyzed result, the 126 l/sec discharge can found. The most important discharge is withdrawing from Ngebel lake and Kaponan spring. The water from Ngebel Lake is used not only for supplying domestic water but also for non-domestic water supply, especially for agricultural purpose. Therefore, it is necessary to analyze the water balance of Ngebel Lake in detail. The specification of some water resources used to fulfill the water balance lack is shown in Table 17. The condition of Ngebel Lake and Kaponan spring is shown in Figures 4 and 5, respectively.

Table 17. Spring water resource in Ponorogo city.

	Name of Spring	Discharge (l/sec)		Name of Spring	Discharge (l/sec)
1.	Sangu Banyu	6	5.	Base	7
2.	Jambu	4	6.	Argo Ploso	10
3.	Parang Kulon	4	7.	Kaponan	60
4.	Pasang	7	8.	Ngebel lake	100 - 1,500

Figure 4. Ngebel lake.

Figure 5. Kaponan spring.

The Trenggalek city domestic water demand in 2008 is 75.31 l/sec. The availability of water supply is 25.61 l/sec. Therefore, the water balance is negative 49.71 l/sec. For year 2015, the domestic water demand is equal 94.8 l/sec. The water balance in this year is negative 69.8 l/sec. To fulfill the lack of water demand, the potential water resources discharge surrounding Trenggalek city was investigated. Finally, the 117.8 l/sec. water discharge was found. This discharge was collected from many spring surrounding Trenggalek city. Piping systems was applied to support the water supply to the city. Some of spring water located surrounding Trenggalek city is used to fulfill the lack of water balance in Trenggalek city is shown in Table 18. The pictures of one of spring water used to fulfill the lack of water balance is shown in Figure 6 and 7, respectively.

Table 18. Some spring water resource in Trenggalek city.

	Name of Spring	Discharge (l/sec)		Name of Spring	Discharge (l/sec)
1.	Sumber Unci	27	5.	Sumber Gemah	70
2.	Sumber Songo	47	6.	Sumber Gador	31
3.	Sumber Klumit	40	7.	Sumber Putuk	30
4.	Sumber Wulung	25	8.	Sumber Bayong	450

Figure 6. Sumber Bayong spring.

Figure 7. Sumber Gemah spring.

From the three cases of research areas, almost all the water balance between domestic water demand and water supply is negative. There are many potential water resources surrounding the research areas, but is not fully exploited to increase the water supply. From the field observations, the most problems is the infrastructure to withdraw the water from spring location to the cities. The meaning of infrastructure here are piping system, water treatment system, and spring water discharge regime. The second problem is some springs discharge are discontinued in the middle of dray seasons. Therefore, it is necessary to manage the watershed to protect the spring discharge during dry season. In this research, the domestic water demand is analyzed with assumption that only 60% of population were served. If the population served is 100%, the domestic water demand will increased by a significant amount. The non-domestic water demand is not taken account in the analysis. The non-domestic water demand for livestock and fishpond usually is supplied from groundwater withdrawing by pumps. For agriculture water, irrigation system is used to supply with technical, semi technical, and manual systems. The water is withdrawing from river, lake, and dam.

5 CONCLUSIONS

From the analyzed results, it can be concluded several important items due are to the research problem and research purpose. The conclusion can be described as follows. In the area with two seasons (rainy and dry seasons), it is very important to predict the water resources discharge during dry season to fulfill the water demand along a year. In cases of Pacitan, Ponorogo, and Trenggalek cities in East Java Province Indonesia, the potential of water resources surrounding those areas are necessary for supplying the domestic water demand. In case of Pacitan city, the water discharge come from spring water it can be used to fulfill the lack of water discharge during dry season. For Ponorogo city, the lack of water balance during dry season it can be fulfilled from the water discharge mainly from the Ngebel Lake. Some water discharge also can be collected from spring water with small volume. The third area is Trenggalek city, which is the lack of water balance during dry season can be fulfilled using water discharge from spring water only. Finally, in general it can be concluded that to fulfill the water balance lack of water supply and water demand for domestic used during dry season the water coming from spring and lake (surface water) can be used. To conserve the water discharge of spring water and surface water especially during dry season, it is suggested that protection of land use in the watershed area of each spring water point should be done.

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GREY WATER USE AS AN ALTERNATE RESOURCE

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ABSTRACT

Water is the life sustaining resource present on earth. Rising population, extensive use, increasing water demand, depleting ground water tables and decreasing water availability have forced the researchers and policy makers to find an alternative source for proper optimization of this life sustaining resource. Water sources available are surface water, ground water and rain water. Fast growing industrialization has already caused enough damage to fresh surface water sources. Rainfall behavior is uncertain and non-homogeneous and can't be relied to fulfill constantly increasing water demand and heavy reliance on ground water is leading to gradual depletion of water table. Thus in this scenario, grey water reuse is an efficient alternative to be used as a water source. Grey water is wastewater generated from domestic activities such as laundry, dishwashing, and bathing. Depending on the type of grey water and its level of treatment, it can be reused for various purposes like irrigation, flushing, floor washing, watering gardens, automobile washing etc. Studies have suggested that recycling grey water can save up to 70% of fresh water consumption. Instead of mixing it with sewage, grey water can be stored in big reservoirs, ponds having provisions of required aeration and it could efficiently serve as an alternate water resource. This stored water can be used for variety of purposes. If stored in large amount with sufficient head it could also be used in generation of hydro-electricity. The present study presents an idea in which grey water can be used to generate hydroelectricity in high rise buildings, present a model of a treatment tank along with overview of the use of grey water globally, discussing different ways and ideas in which it can be used efficiently and economically.

Keywords: Grey water; aeration; hydroelectricity, industrialization, reservoir.

1 INTRODUCTION

In this fast growing world where different countries are still struggling towards sustainable development, water scarcity is one of the major problem faced by society. Starting from domestic to both industrial and agriculture water needs, each sector is the victim of this crisis. Several studies have shown the impact of water crisis. United Nation (UN) estimates that, in 1.4 billion cubic kilometers of water on earth, just 200,000 cubic kilometers represent fresh water available for human consumption (Alam et al., 2012; Gupta et al., 2014). It is projected that by 2025 about two-thirds of the world population will live in water stressed countries (report by pacific institute). There are at least 1.1 billion people without access to a safe water supply and about 2.5 billion without adequate sanitation systems and the majority of them live in developing countries. Thus, there is an urgent need to critically look into the alternate sources of water. Talking about alternate sources, rainwater is the first option that comes into the mind but the major problem with rain is that it is uncertain and non-homogeneous and could not fulfill the constant demand of water. Expanding industrialization has highly reduced the surface water source. Problem with desalination is the mineral decomposition of potable water, thus in this scenario grey water use is a highly efficient option to be used as an alternate resource.

Grey water is the waste water generated from bathrooms, basins, laundry, kitchens etc. Water from bathroom generates around 50-60% of total grey water. Water used in cloth washing generates around 25-35% of total grey water (Alam et al., 2011). Water from kitchen is categorized as dark grey water due to high load of impurities. In normal practice, grey water is combined and drained with sewage (black water). However, it is much less contaminated and requires a lower degree of treatment. The treated grey water can be used for different purposes. Table1 clearly depicts the difference between water quality parameters in grey water and sewage (Rana et al., 2014). It could be seen that biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are much higher for sewage water than grey water. BOD is the amount of oxygen required by micro-organisms to break down organic matter present in given water sample into simpler forms. It is a measure of biodegradable form of organic matter. COD is the amount of oxygen required to oxidize organic matter in given water sample. It is a measure of both biodegradable and non-biodegradable form of organic matter.

Table 1. Comparison of water quality parameters of grey water and sewage.

Parameter	Unit	Grey Water	Sewage
pH	-	6.4-8.1	5.5-8.5
Suspended Solids	Mg/l	40-340	100-350
BOD_5	Mg/l	40-50	100-300
COD	Mg/l	100-300	175-600
Nitrogen (Total)	Mg/l	2-23	30-60
Phosphorus	Mg/l	0.1-0.8	7-20
Turbidity	NTU	15-270	-

Different countries in the world have started to realize the importance of grey water and began to reuse it for various purposes. Some countries have even the standard codes and guidelines for reuse of grey water while in other it is being used without any standard code.

Out of all the continents, North America is the only continent which leads the way in utilizing grey water potential. In North America, grey water use is substantially increasing especially in USA and Canada. In USA, about 20 states are using grey water. Some states in USA that are using it on a large scale include California is the first state in US to impose grey water regulations. A law was passed in 1992 to legalize grey water use. California have standard codes for grey water reuse California Gray water Code – CAC (Title 24, Part 5, Appendix J, grey water system for single family dwellings).This code defines grey water as untreated wastewater that has not come into contact with toilet waste. It does not include waste water from kitchen sinks and dish washers. There are certain guidelines listed by the code which needs to be followed in any grey water reuse system in California. In Arizona, a three-tiered approach is developed for regulation of grey water by the Arizona Department of Environmental Quality, 2001. Tier 1 applies to residential use that uses less than 400 gallon per day. No permission is required for using grey water system for tier 1. Tier 2 is applied when grey water usage is between 400 to 3000 gallons per day while for tier 3 it is more than 3000 gallons per day. Permission is required for authorization in tier 2 and 3 only. Mexico is also using a tiered approach similar to Arizona. According to a law passed in 2003, no permission is required for using grey water reuse system at households. Washington State also issues guidelines for the use of grey water for subsurface irrigation (drain-field or drip irrigation) of ornamental plants, provided certain design requirements are fulfilled (Fact sheet, 2005).

Apart from USA, grey water usage has also increased in Canada although it's not as widely as used as in USA. There are 6 provinces in Canada that provides permission for grey water reuse practices. British Columbia (BC) is the only province with active grey water regulations. Grey water use in South America is much less as compared to North America. However in South America, more than 80% of people live in urban areas thus producing a large amount of grey water and hence there is a huge potential for its use. Private firms like HUBER Solution Grey is installing grey water treatment systems in many countries in South America like Argentina, Brazil, Chile, Columbia, Costa Rica and Mexico.

Africa is facing the problem of increasing population and hence there is an increasing fresh water demand. As per report by (WHO, 2000), the African continent have the lowest total water supply coverage with only 64% of population having access to improved water supply (Bahri et al., 2015). Thus grey water reuse is the necessary solution for Africa. Use of grey water is not very extensive in Africa but still there is some progress in parts of South Africa. Also in some countries like Ghana, Tunisia and Ethiopia grey water is being reused.

Australia is the driest continent and always had limited availability of fresh water. The State Water recycling strategy (DOW, 2008) and Water Corporation's water forever strategy (Water Corporation, 2009) have been developed to deal with the water demand issues. Finally, a code was made in 2010. "*Code of practice for reuse of grey water in western Australia" (2010).* This code has listed certain guidelines on the use of grey water in western Australia. Grey water use for garden irrigation is the most common practice. Due to high installment cost, the government in Australia is providing subsidy for grey water reuse systems. There are many private firms and companies that are installing the grey water reuse system at household level. Australian firm Nexus eWater has found a way to recycle the soapy grey water that goes down the drain and harness the heat from it to warm up clean water. Direct grey water reuse for garden irrigation is being examined by some Australian water authorities as an option for reducing fresh water demands. Some grey water systems available in Australia are Aqua Reviva, Perpetual Water - Home® System, Nylex Grey water Diverta, Home Water Bowser Grey water Wheelie Bin, Eco-Care Grey Waste Water Diverter, NETA H2grO Grey water Diverter System. (Vallee et al., 2014) Government has also started subsidizing the installment of grey water treatment systems.

In Europe, grey water use as an alternate resource is gaining popularity. In Spain, since 2002 more than 50 municipalities have approved grey water reuse systems in new buildings. In UK, grey water is used only for toilet flushing and still its use for irrigation purposes is not permitted. Grey water systems available in Europe are Aqua Cycle of PONTOS and Ecoplay.

Asia's water availability per capita is 4200m^3/capita per year which ranks lowest in the world. World average water availability per capita is 7000m^3/capita per year. It is predicted that by 2025 there will be a decrease of 15-35% in water availability per capita in the region (ADB, 2001). Seeing the rising demand and decreasing water availability, grey water reuse is a very efficient option to use as an alternate resource. Grey water use is important because it restricts water demand and reduces stress on treatment system. With increase in population, there will be an increase in stress on sanitation and wastewater disposal system. (Gupta et al., 2004) predicted that recyclable wastewater will meet 15% of total water requirement in 2050. Grey water use in Asia is still in stage of infancy however there is some progress in countries like Israel, Japan, China etc. In Tokyo, Japan grey water use is mandatory to all the buildings having area greater than 30000 sq. m or potential non-potable demand of more than 100 cubic meters per day. Government in Japan is providing up to 50% subsidy for installment of grey water treatment systems. In Israel ministry of health has published guidelines in 2008 permitting grey water reuse for flushing and watering gardens and since then various grey water system are being authorized to operate. In Mumbai, India grey water reuse is compulsory for all new building projects having size 20,000sq feet and above. In China the ministry of housing and urban rural development published a report in 2012 claiming that total amount of reused water in China has reached 3.37 billion cubic meters in 2010 (Zhong et al., 2013). So, with time grey water use in Asia is increasing progressively and with growing awareness its scope in near future is predicted to be substantially high.

Water and energy are the two driving forces of modern civilization. Energy and water are required by all the sectors such as industrial, domestic, agriculture etc. The demand for both these resources is increasing at a high rate with time, thus there is an urgent need to balance this water and energy demand. Thus, the primary target is not just to solve the problem of water crisis but at the same time there is a need to develop a sustainable source of energy. The main objective of the present study is to develop a plan for grey water use in generation of electrical power from high rise buildings and propose a model for a suitable treatment tank for the treatment of the grey water to be used for various possible purposes.

2 HYDROELECTRICITY GENERATION IN BUILDINGS USING GREY WATER

With the limited land availability and rising population, people are forced to utilize the large vertical space and thus the high-rise buildings are very common nowadays. The height of the buildings is progressively increasing with increasing population.

In high apartments where large number of people are residing, a large amount of grey water is being produced. This grey water is generally combined with sewage water, treated to meet discharge requirements and is disposed into the water bodies. This paper suggests the idea of storing grey water at suitable head and then using it to generate hydroelectricity. After the generation of electricity, it can further be stored in a tank providing suitable treatment and can be used for various purposes.

A high-rise building can be assumed to have 40 floors. Studies suggests the following steps to generate hydroelectricity from grey water.

- A water collection tank is placed at about 20th floor of the building. Grey water generated from all the above floors is collected in this tank.
- This collection tank uses a water level sensor. After the required volume of water is collected in the tank, sensor actuates a valve at the bottom of the pipe connected to the tank (Sarkar et al., 2014).
- The valve is opened and the water is allowed to fall on the blades of turbine and thus rotating the turbine shaft.
- Selection of the turbine is done on basis of provided head and flow rate. Francis turbine can be used as it is designed for a medium head varying from 60-150 meter (Inamdar et al., 2016).
- The turbine is further coupled to an AC generator via a gearbox. Use of a gearbox is justified to achieve the desired RPM for the generator to obtain a steady output frequency.
- AC generator is further connected to rectifier that converts AC to DC. It is further connected to battery which enables us to use it later.
- The inverter is synchronized to 230 V and then this electricity can be connected to the building.

3 DESIGN OF ENERGY GENERATING SYSTEM

Salient features of design of energy generating system are demonstrated herein.

3.1 Overall setup of generating unit

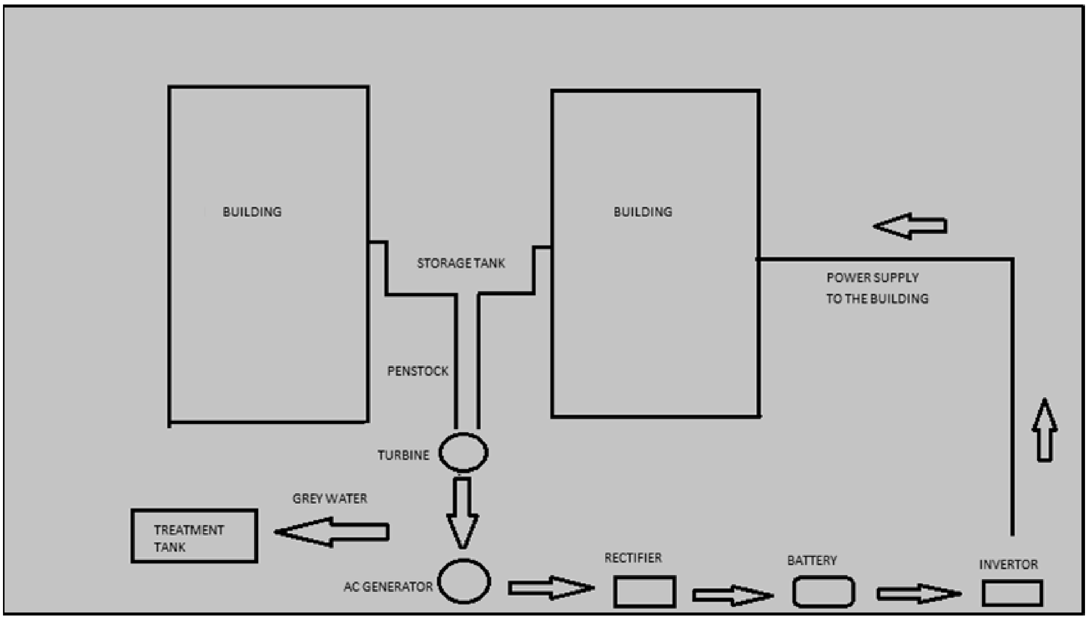

Figure 1. Schematic diagram of energy generation system.

3.2 Design of storage tank

The tank would be made up of concrete with required reinforcement. If it is exposed to sunlight then it can also be covered with solar panels which would be an effective method to produce additional electricity. The area of tank is 64 m^2. Height of the tank in no case should exceed 3.5 m with respect to structural limitations.

3.3 Design of penstock

The work of penstock is to deliver the water from tank to turbine. The target in designing of pen stock is to ensure that head loss is minimized and at the same time cost is also an important consideration.
Head loss due to friction is given by:

$$Hl = 4flv^2 / 2gD \qquad [1]$$

Decreasing the diameter of pipe would reduce the cost but at the same time increase the head loss.

Take pipe of diameter 50mm.
Material of the pipe would be PVC as it has a lower value of friction factor (0.0015).

3.4 Sample calculations of possible generation of energy

Take a sample building having 40 floors.
Water is stored at a height of 20th floor.
Approximate height of 20th floor (h) = 70m
Average amount of grey water generated in 1 day from a single family = 400l
Assuming 15 families to be living on each floor.

Total amount of grey water collected from a single floor = 400×15 = 6000l [2]

Total amount of grey water collected in 1 day from 20 floors = 120000l or 120m^3. [3]

Velocity of flow = $\sqrt{2gh} = \sqrt{2 \times 9.81 \times 70}$ = 37 m / sec [4]

Area of penstock = 0.0019 m^2

Flow rate (Q) = A×V = 0.0704 m^3/s [5]

Water power = ρgQh/1000 KW [6]

Therefore:

$$\text{Water power} = \frac{1000 \times 9.81 \times 0.0704 \times 70}{1000}\ \text{KW} = 48.34\text{KW} \qquad [7]$$

Considering overall efficiency (both hydraulic and mechanical) to be 90%:

0.9 = shaft power/ water power => shaft power = 0.9×49.44 = 43.51KW [8]

43.51KW of power will be generated for a discharge of $0.0704m^3/s$ and a head of 70m.
Total time required = 120/0.0704 seconds = 1705.54 seconds = 28.4 minutes = 0.473 Hr.
No of units of electricity generated in 1 day = 20.6KWH
1 CFL bulb takes 0.015KW of power to produce a light of 800 lumens
200 such bulbs can be lighted for 7 hours from the electricity produced.
In 1 month, units of electricity generated = 640 KWH
If water from 3-4 buildings is collected in same tank then amount of electricity generated in 1 month will rise to about 2560 KWH

Now based on these sample calculations, amount of electricity generated for various heights of building can be calculated.

Table 2. Amount of electricity generated for different heights in a building.

Building Height (floors)	Height of collection tank (floor)	Head (m)	Area (m^2) 10^{-4}	Velocity (m/s)	Discharge (m^3/s)	Power generated (KW)	Volume of water collected (m^3)	Energy generated per day (kwh)	Energy generated per month (kwh)
20	10	35	19	26.20	0.05	15.39	60	5.15	159.66
20	15	52.5	19	32.09	0.06	28.27	30	3.86	119.74
30	15	52.5	19	32.09	0.06	28.27	90	11.59	359.23
30	20	70	19	37.06	0.07	43.52	60	10.30	319.32
40	20	70	19	37.06	0.07	43.52	120	20.60	638.63
40	25	87.5	19	41.43	0.08	60.82	90	19.31	598.72
50	25	87.5	19	41.43	0.08	60.82	150	32.19	997.86
50	30	105	19	45.39	0.09	79.95	120	30.90	957.95
60	25	87.5	19	41.43	0.08	60.82	210	45.06	1397.01
60	30	105	19	45.39	0.09	79.95	180	46.35	1436.92
60	35	122.5	19	49.02	0.09	100.74	150	45.06	1397.01
70	30	105	19	45.39	0.09	79.95	240	61.80	1915.89
70	35	122.5	19	49.02	0.09	100.74	210	63.09	1955.81
70	40	140	19	52.41	0.10	123.09	180	61.80	1915.89

From the table, it is seen that maximum amount of electricity is generated when collection tank is placed at half the height of building. Thus, the optimum height for collection tank is half of the height of building. Higher the building, higher is the amount of electricity produced.

A single collection tank can also be built for 2 or more buildings to get more efficient results. After the generation of electricity, the grey water can be stored and treated in a treatment tank.

3.5 Design of treatment tank

The grey water from the turbine is passed through the treatment tank shown in Figure 2. This tank can be made up of concrete covered by wire mesh to control birds and other solids impurities to come in contact with water but at the same time favour natural aeration. Treatment tank consist of three compartments.

3.5.1 Compartment 1

This compartment consists of a bed of fine sand, coarse sand and gravels which act as a filter media for grey water. An experiment was conducted and various water quality parameters were found out before and after passing the domestic grey water sample from a filter media as shown in compartment 1 (shown in table 3). The experimental setup is shown in Figure 3. The sample was collected from a residential house.

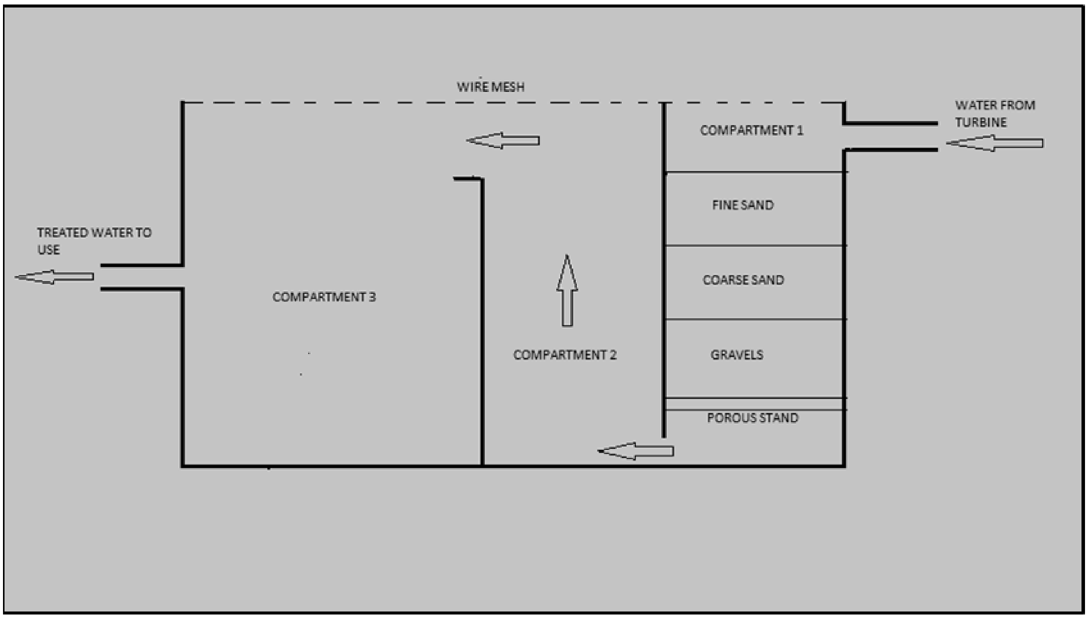

Figure 2. Layout of treatment tank.

Table 3. Comparison of water quality parameters of grey water sample and treated water.

Water Quality Parameters	Grey Water Sample	Treated Grey Water
pH	7.54	7.14
Alkalinity	384 mg/l	310 mg/l
Total hardness	154 mg/l	140 mg/l
COD	328 mg/l	144 mg/l
BOD_5	35 mg/l	10 mg/l
Chloride	60 mg/l	50 mg/l
Turbidity	93 NTU	3 NTU

From Table 3, it could be seen that there is vast improvement in quality of water. There is a considerable reduction in BOD, COD and turbidity. Turbidity almost vanishes and water becomes clear as could be seen in Figure 4 .

The flow rate through this filter was found to be 0.077 $cm^3/sec/cm^2$. Area of the filter will depend on the volume of grey water to be treated.

Figure 3. Filter for compartment 1.

Figure 4. Raw sample and filtered sample.

After passing through this filter grey water is passed into the second compartment.

3.5.2 Compartment 2

This compartment acts as a carrier tank to transfer grey water from compartment 1 to compartment 3. Here water rises against the gravity. In this compartment, some disinfectant may also be added if required or bleaching can be done to prevent odor problems. Some flocculating agent may also be added if colloidal impurities still persist. Water from this compartment is allowed to fall into compartment 3.

3.5.3 Compartment 3

Here no treatment is given except natural aeration. When water falls from compartment 2, turbulence increases and so does the water-air interfaces. This results in increased aeration.

Increased aeration will increase the dissolve oxygen concentration, oxidize reduced compounds and control odor problems.

Other treatments can also be given as per the requirement.

From this tank, the water can further be used for various purposes like irrigating plants, watering fields, floor washing, Car washing, Toilet flushing, Road cleaning, Construction work etc.

4 CONCEPT OF SEPARATE GREY WATER LINES

This concept is advisable for developing towns or in designing of any new city. Grey water should be separated from sewage water. Like sewer lines, there should be separate lines for grey water. Required connections should be made at each household to separate grey and black water lines.

Table 4. Approximate amount of waste water generated in domestic premises (Latha et al., 2005).

Source	**Total waste water**		**Total Grey water**	
	L/day	**Total (%)**	**L/day**	**Total (%)**
Toilet	186	32	-	-
Hand basin	28	5	28	7
Bath/Shower	193	33	193	48
Kitchen	44	7	44	11
Laundry	135	23	135	34
Total	586	100	400	100

From Table 4 it could be depicted that a large amount of grey water is being produced in domestic premises and thus through grey water lines, large amount of grey water can be collected and then used in different ways. Some ways in which this collected grey water can be used are:

4.1 Collection reservoir (Grey water pond)

The water from these lines can be collected in a collection reservoir. This water would be aerated naturally. Some preliminary treatment may also be given to avoid odor problems and colloidal impurities. While designing the reservoir layers of different elevations can be provided which would increase the turbulence and increase the air – water interfaces and hence resulting in increased aeration. From this reservoir water can used and diverted for various purposes, it could also be used to generate electricity.

4.2 Recharging of dry ponds

Grey water from these lines could be used to recharge dried ponds. Ponds are major contributors to local ecosystem richness and diversity for both plants and animals.

4.3 Irrigating fields/ farms

This grey water can also be used for irrigating fields after giving the required treatment. This would not only help to increase production yield but at the same time large amount of fresh water could be saved.

5 CONCLUSIONS

With the rising water demands and decreasing fresh water sources, it is evidently clear that there is an urgent need to look out for alternate sources of water. The present study suggests the use of grey water for generating electricity in high rise buildings and proposes a model of a treatment tank to treat the grey water. It also reviews and suggests the grey water use as a required alternate source which can be used to meet the constant water demand throughout the year and at the same time save a large amount of fresh water. It is much more efficient and economical than wastewater treatment. It requires lower degree of treatment. With time, many countries throughout the world are realizing the importance of this new potential but still its use is in the stage of infancy. Major problem that interferes in its growth is high installment cost. To remove it in many places like Australia and Japan, government is providing subsidies for its installment. Once installed the future benefits are overwhelming. Thus, there is a need for government and concerned authorities to invest in this sector. In designing of new cities, concepts of separate grey water lines and large grey water reservoirs can be very beneficial. In high rise buildings, it could also be used to generate electricity which can further be used for different purposes by passing through a treatment tank. To sum up, as per time requirement there is a need to differentiate between grey water and sewage and increase its use more efficiently to develop a sustainable environment.

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