Need for paradigm shift in design philosophy for tasks involving water - energy nexus

Chandrasekaran Sivapragasam*, Ayyathurai Kowsiga and Ganesan Lidwin Joan Jeraldine

*Senior Professor, Department of Civil Engineering, Kalaśalingam Academy of Research and Education, Krishnankoil – 626126, Tamil Nadu, India.

Under Graduate Student, Department of Civil Engineering, Kalaśalingam Academy of Research and Education, Krishnankoil – 626126, Tamil Nadu, India.

*Corresponding author email – sivapragasam@klu.ac.in

Abstract. Since both water and energy are highly vital and scarce resources, for the sustainability of any economic development plan (either at macro level or micro level), it is necessary to consider the interconnection between water and energy. Alternative strategies should be explored which considers this interconnection. This necessitates a paradigm shift in the design procedure/philosophy itself, the initiatives towards which are still in inception. This work proposes a typical design philosophy concerning water energy nexus and demonstrates its application at a university level scenario for augmentation of drinking water requirement. Three alternative strategies are considered for augmentation namely locating additional bore wells within the campus, reuse of treated sewage water for toilet flushing and utilizing wasted runoff from the upstream during rainy seasons. The alternatives are analysed to evaluate their merit in savings in energy utilization and water generation. The third alternative consisting of constructing a retention pond to collect the runoff water is found to be most viable which contributes most optimally towards savings in energy requirement as well as meeting the needs of water requirement. While reuse of treated wastewater contributes to 45000 l/day of water, it comes at the cost of 490 kWh/day. The construction of detention pond generates 200000 l/day of water during monsoon seasons which can used to meet water requirement as well as recharge of the groundwater. The energy requirement can be made almost nil by transporting the water under gravity flow.

Keywords: Water, Energy, Sustainable Development, Framework

1. Introduction

The interdependency between water and energy (the two major critical resources) is gaining interest throughout the world. The water and energy experts, after years of attempt in solving the problem separately, are now realizing that these two fundamental natural resources can no more be seen in isolation. Considering this interdependency, it behoves one to understand that any project planning involving water and energy must address this fact most optimally in order to achieve sustainable development.
From a global perspective, the existing research concerning water-energy nexus has covered a large scope in terms of attempts in revealing the interconnection from as small a scale as a single appliance or household level to as large as an entire nation. For instance, a holistic framework to provide sustainable scenarios that include feasible infrastructure intervention for the case study on Matagorda County, Texas was recently reported [1]. The study develops a Water - Energy - Food (WEF) Nexus model that identifies the causes of water stress, and provides scenarios, including feasible infrastructure interventions, from which to draw sustainable recommendations that take into account the nexus interlinkages unlike conventional methods. Towards this, the study proposes a three step approach viz., identifying scenarios (different scenarios formed by various combinations of infrastructure intervention to mitigate risk and vulnerability in preserving primary resources); developing a WEF nexus platform for quantitative assessment of the trade-offs associated with various scenarios; and formulating criteria for optimal scenario with respect to environment, social and economic sustainability. A recent review reported some of the water-energy (W-E) nexus scenario and identified many major gaps which include energy use associated with water in industrial and commercial operations [2]. Many other recent works contributed to different aspects of addressing this nexus issue [3-5].

Despite the reported research, the systematic understanding of water-energy interrelationship is in its inception. More importantly, despite the potential in the holistic approach undertaken by various studies, there is a gap between research and actual real time implementation. Moreover, sufficient documentation of the success and failures associated with the holistic approach, the associated data and tools are necessary in all the decision-making process involving water and energy [6].

To the authors' knowledge, in India, studies concerning water-energy nexus are still in inception. For instances, Rasul et al. [7] insisted that water energy nexus approach can be improved by understanding the interconnectedness between the system but it needs a major shift in decision making process. A framework is suggested for food, water and energy nexus to manage the challenges. Sinha et al. [8] reported that water and energy are the significant factors for agriculture, the absence of suitable policies in managing the groundwater and energy leads to over-exploitation. Given the fact that demand for freshwater and energy in the country is expected to increase in the coming years due to the impact of population mobility, initiatives for economic development and also more importantly climate change, both water and energy are very vital and scarce resources, and hence it is high time that practical initiatives are taken at all the levels (micro level and macro level) to change the design philosophy in engineering applications involving water and energy, wherein all the planning is done taking into account the water-energy nexus.

This study considers the W-E nexus scenario of a university campus in augmenting the water requirement of one of its hostels. First a design philosophy is presented which is implemented for the said case study. Three different scenarios are identified and analyzed for its suitability and final recommendation is arrived at.

2. Proposed Design Philosophy
A typical design philosophy is illustrated in Figure 1, which consists primarily of three stages viz., Stage I, Stage II and Stage III. Stage I deals with identification of the existing engineering problem, analyzing its water and energy requirements, and arriving at the interlinkage between water and energy i.e. how the change in one will reflect on change in the other. Stage II is the intermediate stage where it is recommended to identify alternative strategies that could provide options for choosing to optimize the W-E nexus. The alternative strategies might need some intervention in terms of new infrastructure facilities to be constructed or some modifications in the existing system. At this stage, it is also necessary to identify the tools and methods that are required to analyze the alternative strategies including the analytical methods, software simulation etc. Stage III is the output processing stage wherein the strength and weakness of the different alternative strategies are analyzed with respect to W-E nexus and the optimal solution is arrived at.
3. Study Area
The proposed method is demonstrated for augmenting the water requirement of our university campus community, Kalasalingam Academy of Research and Education (KARE), Tamil Nadu. First data is collected on water and energy usage in the campus. At present, the community depends mostly on treated groundwater from water treatment plant inside the campus and partially on procuring water from outside sources, both of which put demand on the energy (pumping from bore wells, treatment of water, and for outside sources, fuel used for the water tankers which are converted to equivalent energy). The details of water requirements and its sources are listed in Table 1.

| Water Sources       | Water Requirement (l/day) | Energy required (kwh/day) |
|---------------------|---------------------------|---------------------------|
| Inside KARE         | 1,00,000                  | 180                       |
| Outside KARE        | 72,500                    | 1336                      |
| Total Water Requirement | 1,72,500              | 1516                      |

The water requirement is estimated assuming 115 l/day for an inmate strength of 1500 which includes water use for cooking and cleaning in the mess. About 1 lakh litres of water is obtained from internal bore wells sources which are treated in the water treatment plant situated inside the campus. The treatment of this quantity of water requires about 180 kWh/day of energy. The balance water requirement is procured from outside sources for which energy equivalent of the water tankers used for carrying water is estimated.
4. Results & Discussion

From the collected data, the existing W-E nexus is estimated. To bring optimal use of W-E, three alternative strategies are considered viz., locating additional bore wells and associated energy requirements thereof (alternative strategy I); using the water from sewage treatment plant pumped to be used for toilet flushing (alternative strategy II); and constructing a storage pond upstream of campus catchment and thus generating additional water to be supplied through gravity flow to save energy (alternative strategy III).

4.1 Alternative Strategy I

The first strategy is to locate additional bore wells in order to augment the water requirements. Based on the data collection the water requirement for one hostel is 174685 l/day (Table 1). The procurement from outside sources can be minimized by adding additional bore wells. For the geological formation in the campus, based on the already existing bore wells and their yield, at best 2 bore wells can be provided in the proximity of the hostel. The yield, on an average, is expected to be 30,000 l/day demanding an energy requirement of 89 kWh/day to pump that water. Since the campus is in a semi-arid region, it cannot be fully ascertained if these additional bore wells will actually cater to the water requirement throughout the year.

4.2 Alternative Strategy II

The second strategy that is proposed is to use the treated sewage water for toilet flushing (and thus save fresh water utilization for flushing). Assuming 30 l/day per person towards this need, the total water requirement for toilet flushing would be 45,000 l/day. The associated energy requirement for this comes from two perspectives viz., (a) the energy required to treat the sewage water in the sewage treatment plant and (b) the energy required to pump the treated sewage water from the treatment plant to the hostel against a head of 7m. The hostel is located about 7m higher than the location of the sewage treatment plant. From the design perspective, to pump the treated water at the rate of 6.25 l/sec for 2 hours against gravity and the energy required for the sewage water treatment, the total energy requirement is estimated to be 490 kWh/day.

4.3 Alternative Strategy III

Under this strategy, it is planned to construct a retention pond upstream of the hostel. The upstream of the campus is located just in the foothills of the Western Ghats mountains and as such is characterized by steep slope leading to high runoff generation potential. The proposed infrastructure intervention is in terms of construction of a pond to collect this runoff, the catchment area of which is about 7 ha guaranteeing conversion of almost the entire rainfall falling in this catchment into runoff. The region gets rain during the southwest monsoon and the north east monsoon during which the hostel is functional. Hence, if this water is properly tapped and utilized it will cater to substantial need without energy consumption in transporting the water. The commonly used SCS-CN (Soil Conservation Service Curve Number) method is used for estimating daily runoff from the daily rainfall. A simple pipe system is designed to carry the water under gravity flow.

To identify the exact location of the pond, the elevation contours of the proposed catchment is obtained using Google Earth Pro from which stream flow path are identified (Figure 2). The designed runoff volume using is estimated for a rainfall intensity associated with a rainfall event of 5 hours duration and 8 years return period. The design rainfall is estimated to be 138mm. The corresponding runoff volume is estimated to be 7554.3 m$^3$. The storage capacity of the pond is calculated by using the Sequent Peak Algorithm and is estimated to be 3000 m$^3$.

The W-E consumption matrix is shown in Table 2. Although the alternative strategy II helps in re-use of the waste water, the associated energy requirement forbids its usage as far as striking a balance between W-E is concerned. It is, therefore, advisable to go for utilizing the otherwise wasted runoff...
water for the needs of the hostel which doesn't require any additional requirement. Since the runoff water is expected to contain suspended solids load and is not expected to contain any other impurities, it is sufficient to give required time for settling of these loads in the pond itself. Otherwise, the water can be directly utilized without any other additional treatment and thus avoiding need for additional energy. The only issue that will arise will be due to failure of monsoon in a given year, in which case, it may not be possible to meet the water requirement. Considering all this, it is suggested to go for both Alternative Strategy I as well as III. In the normal times (where monsoon runoff is available), the Alternative Strategy III can be used, and the Alternative Strategy I can be used for emergency.

If fact, during good monsoon days, the additional water can be used to recharge the groundwater and thus add to the usefulness of Alternative Strategy I. It is to be noted that the energy requirement associated with the construction of the pond as well as the providing of the bore wells is not taken into consideration in this study.

| Alternative Strategy | Water Yield (l/day) | Additional Energy Required (kwh/day) |
|----------------------|--------------------|-------------------------------------|
| 1                    | 30,000             | 89                                  |
| 2                    | 45,000             | 490                                 |
| 3                    | 2,00,000           | Nil                                 |

5. Conclusion
Based on this study, the following conclusions are drawn

a) As a holistic approach, to preserve the two important natural resources, namely water and energy, it is recommended that any planning takes care of the water-energy nexus.

b) The existing water-energy nexus scenario to meet the water demand of one of the hostel in the university campus community is studied and it is seen that a 725000 litres per day of water is procured from outside involving about 1330 kWh/day of energy requirement. To address this, three different alternative strategies are proposed.

c) The proposed infrastructure intervention in terms of construction of a detention pond is useful to generate about 2,00,000 litres/day of water during monsoon days and can be easily meet the water requirement of the hostel without incurring any additional expenditure on energy.
d) The surplus water during excess rainfall which is taken through the emergency spillway for groundwater recharge can also be used for supplementing the water needs. However, there will be energy requirement in terms of pumping the water.

Reference
[1] Kulat, M I Mohtar R H and Olivera F 2019 Front. Environ. Sci. 7, pp 1-12.
[2] Kenway S J, Lant P A, Priestley A and Daniels P 2011 Water Sci. Technol. 63(9), pp 1983-1990.
[3] Yin Z, Jia B, Wu S, Dai J and Tang D 2018 Water 10(4), 385.
[4] Fang D, Chen B 2017 Appl. Energy 189, pp 770-779.
[5] Larsen M A D, Drews M 2019 Sci. Total Environ. 651, pp 2044-2058.
[6] Daher B, Mohtar R H, Davidson S, Cross K, Karlberg L, Darmendrail D and Fonseca G 2018 Int. Water. Resour. Assoc. 4.
[7] Rasul G 2016 Environ. Dev. 18, pp 14-25.
[8] Sinha S Sharma B R and Scott C A 2006 Groundwater research and management: Integrating science into management decisions pp 242-257.