

Environmental and Social Impacts of Mini-hydropower Plants—A Case Study from Sri Lanka

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Abstract: This research study was conducted to review the environmental and social impact of mini hydropower plants (run-of-the-river type) by selecting Denawaka Ganga mini hydropower plant, which is located in Ratnapura district, Sri Lanka. Field visits and discussions among the authors, authorities and the residents were carried out. Then, the environmental and social impacts were scientifically analysed using regulation degree (RD) and environmental impact value (EIV) scores. It was found out that the Denawaka Ganga mini hydropower plant has induced some environmental concerns; however, significant positive social impact to the society. This is in addition to the green energy generation. Therefore, it can be concluded herein that the Denawaka Ganga mini hydropower is an asset to the country, Sri Lanka.

Key words: Denawaka Ganga hydropower plant, environmental impact value, mini hydropower plants, regulation degree, social impacts.

1. Introduction

Hydropower plays an important part of the electricity production in world including Sri Lanka. The total hydropower potential in Norway is 159 TWh per year according to the Norwegian Water Resources and Energy Directorate [1]. Out of this 159 TWh, the annual generation lies around 120 TWh. On the other hand, China expected 194 GW from hydropower in 2010 to support their fast-growing economy [2]. In addition, India is none second to any of the countries in development of hydropower [3]. The usage is popular among many countries because hydropower brings many advantages to the economy and the society of the countries. It is one of the most reliable renewable energy sources to develop the electricity to date in the world [4-6]. In addition, it may be one of the cheapest

renewable energy resources to develop electricity [7-10]. Therefore, many countries look for the potential of hydropower by researching new locations to hydropower development [11-16].

Hydropower projects can be classified into several clusters depending on the generated power. There is no standard or clear cutting rule for the classification [17]; however, it is based on the practice. According to Williams and Porter [18], a large hydropower project produces more than 100 MW. In between 10-100 MW, 1-10 MW, 100 kW-1 MW are called medium, small and mini, respectively. The classification further goes to the smaller levels. In between 5-100 kW are called micro hydropower projects whereas pico hydropower projects if the generated capacity is less than 5 kW [18]. However, according to Rojanamon et al. [17], small hydropower projects vary from 2.5-25 MW of power generation. They further stated the most common value as 10 MW according to Paish [5] and Demirmas [19].

Many of the countries have already developed large

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and medium hydropower projects and now they are eyeing on the small scale hydropower projects [20-23]. Scotland is one of the countries which targets 100% power supply from renewable resources by 2020. They have already established 1.5 GW of hydropower and still has the potential of another 500 MW. However, this 500 MW is largely from small and mini hydropower projects [22].

Sri Lanka benefits around 20% energy demand from hydropower. The Sri Lankan authorities have identified the last couple of major and medium hydropower stations and the government is working towards them. However, energy authorities look for mini and micro level hydropower stations heavily due to several reasons including environmental aspects [24-26]. Nevertheless, some countries like China and Brazil are still identifying the locations for massive hydropower projects due to their energy demand (examples: Lianghekou Dam = 3,000 MW, Shuangjiangkou Dam = 2,000 MW, Baihetan Dam = 1,000 MW in China and Chacorão Dam = 3,336 MW, Jatobá Hydroelectric Power Plant = 2,338 MW, Belo Monte Dam = 11,233 MW in Brazil).

Small and mini hydropower stations have many advantages as well as some disadvantages against the massive hydropower stations. Most of the advantages are along the lines of environmental concerns. Usually, the small hydropower plants are run-of-the-river type hydropower stations. Therefore, there is no reservoir to store the water. Unlike the massive reservoirs, therefore, the damage to the biodiversity in the natural environment in run-of-the-river type hydropower station is minimum [27-28]. Moreover, the emission of greenhouse gases compared to massive hydropower plants is very small [29]. In addition, sedimentation is a significant issue for most of the massive reservoirs [30]. However, run-of-the-river type hydropower stations reduce that concern by usually having sedimentation tank [31]. Even though they are not listed here, there are several disadvantages in small hydropower projects [32-33].

These advantages and disadvantages are discussed locally (on the relevant place of construction) before a hydropower plant is constructed. However, there is minimum attention to the plants after construction, at least in the developing world. In Sri Lanka, the same scenario is practiced. No one really observes scientifically on the developed run-of-the-river type hydropower stations as far as they generate power. However, it is highly important to identify the socio environmental issues developed due to the construction of these hydropower stations because they would be the lessons learnt for the future projects. In addition, the authorities can improve the situation of the surrounding if there are any threatened problems due to the hydropower station. Highlighting this gap in Sri Lanka, we conducted research to identify the environmental and social impacts of a run-of-the-river type hydropower plant (named Denawaka Ganga mini hydropower station) in Sri Lanka.

2. Regulation Degree (RD) and Environmental Impact Value (EIV)

There are several techniques to quantify the environmental damage from a mini hydropower plant. Regulation degree and environmental impact value are two different ways of presenting the damage. Regulation degree is a measurement to calculate the impact caused by the change of hydrological regime characteristics which considered an impact to the surrounding environment in a physical manner [34]. Many researchers have used this to quantify the environmental damage due to newly developed flow structures as well as the climate change [35-39]. This can be presented in Eq. (1):

$$RD = \frac{V_{stored}}{V_{flow}} \times 100\% \quad (1)$$

where, RD , V_{stored} and V_{flow} are regulation degree and the total water volume that can be stored and annual flow volume, respectively. Based on this RD value, the flow regulation's impact on the stream can be classified. Table 1 table gives the classifications.

Table 1 Classification of the environmental impact based on regulation degree [34].

Status	Class	Regulation degree
High	1	0
Good	2	09.99
Moderate	3	1,019.99
Unsatisfactory	4	2,049.99
Poor	5	50,100

The total impact caused to the environment can be calculated using environment impact value (*EIV*). The summation of the impact values gives an overview idea on whether the power plant is a threat or an advantage to the country. The index was not only used to hydropower plants but also many other environmental concerned activities [40-44]. Even though there are various ways of expressing the index in the literature, we have used the mathematical explanation as given in Eq. (2):

$$EIV = \sum_{i=1}^n (V_i \times W_i) \quad (2)$$

where, V_i is the relative change of environmental quality parameter, W_i is the relative importance or weightage of the parameters and n is the total number of parameters.

3. Study Area

Sri Lanka is blessed with water resources. Even though the country is divided into three major climatic

zones (wet zone, intermediate zone and dry zone), the island receives a rainfall of 750-5,000 mm per annum. There are many mini hydropower (run-of-the-river type) plants in Sri Lanka. The story of mini hydropower goes to the British ruling time. Tea plantations in mountainous regions installed small hydropower plants to supply the electricity need of the factory [45]. However, many of them are given up now as they receive the national grid electricity as the energy source. Nevertheless, the governments of Sri Lanka have recently encouraged the private sector to even build new mini hydropower stations as a solution to the energy demand in the rapidly developing country.

Denawaka Ganga mini hydropower station is one of the run-of-the-river type hydropower stations owned by the private sector. It is in Ratnapura district. Ratnapura district is in the wet zone of the country and receives majority of the rainfall during the south west monsoon from May to September of the year [46]. In addition, Rathnapura is treated as a frequently flooding district of the country due to the intensity rainfall [47-49]. The Denawaka Ganga hydropower plant receives runoff water from 172.58 km² catchment.

Fig. 1 shows the catchment area of the Denawaka Ganga hydropower plant. The catchment area is basically a natural forest area with few suburbs. Due to

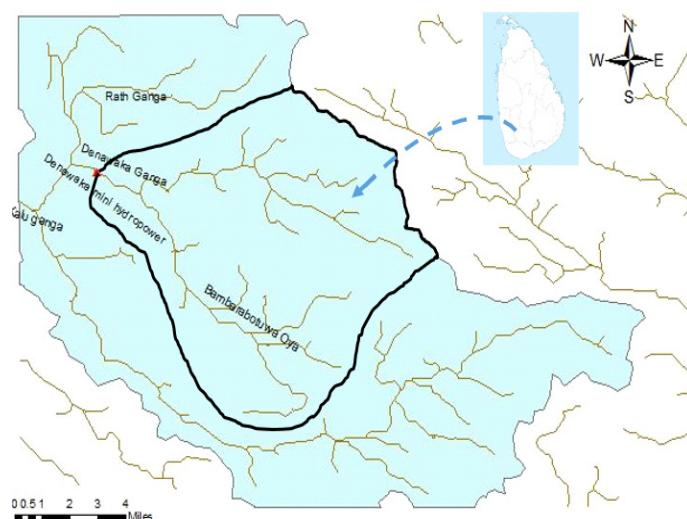


Fig. 1 Denawaka Ganga catchment.



Fig. 2 Intake weir during a dry day.



Fig. 3 Intake weir during a wet day.



Fig. 4 Head raised canal.

the unpopulated catchment area, the water quality has ensured a better quality. Figs. 2 and 3 show the intake weir during the dry and wet weather periods,

respectively. The head raised canal just above the forebay tank is shown in Fig. 4.

The project development was proposed in 2002 with

a build capacity of 4.9 MW. However, after the government clearances, the project construction work started in 2009 with an updated capacity of 7.2 MW. The total investment was 905 million Rupees (\approx 8 million US\$ in 2009). Since 2013 it started to strengthen the national electricity grid by supplying electricity. The power plant consists of four horizontal Francis hydro turbines which are connected to four electricity generators.

4. Approach

Several field visits were arranged to the mini hydropower area and the surroundings during the time from May 2017 to October 2017. These included visiting the power plant, water intake weir and the village around the power plant. We were able to obtain the technical details of the power plant and the intake structures from the authorities employed at the power plant. In addition, we were able to obtain all technical specifications including the design consideration and the economics of the power generation. The digital maps of the area were bought from the survey department of Sri Lanka. These digital maps were used to draw the catchment area of Denawaka mini hydropower plant which was presented in Fig. 1.

The observations drafted from our field trips were used to calculate the *EIV* for the Denawaka Ganga mini hydropower plant. In addition, the National Red List published by the Central Environmental Authority, Sri Lanka, was referenced and to find out the available flora and fauna in the area [50]. The authors do not have subject specific knowledge to identify the whole list of flora and fauna; however, they have witnessed some of these when they are having the field trips. However, it is highly recommended to conduct a biodiversity analysis to identify the potential threats of the mini hydropower station on the flora and fauna.

In addition, we have discussed with the villages on the pros and cons of the mini hydropower station on their daily life. A questionnaire was carried out and identified some important feelings of the surrounding

villages.

5. Results and Discussion

Hydrological regime analysis was carried out with reference to the variation characteristics given in Bergkamp et al. [51]. The followings are the findings:

- The average water flow of the mini hydropower plant is $11 \text{ m}^3/\text{s}$. This was maintained to a stabilized value;
- The Denawaka Ganga's water flow has almost been fully transmitted to the mini hydro power plant through the headrace. Hence there is no variation of the alternation;
- Heavy seasonal rainfalls can be witnessed in the area as it is in the wet zone of the Sri Lanka;
- The river has shorten flood peaks as well as shorten low flows;
- Rapid changes in the river can be observed in a shorter time as the river is prolonged to floods.

Flow magnitude, duration of flow, flow frequency, flood timing and the rate of change were identified as the fundamental characteristics influencing the physical and biological processes in a river [52]. Based on these fundamental characteristics and our above stated findings for Denawaka Ganga, Table 2 can be presented for the flow regime characteristics of the Denawaka Ganga.

According to Table 2, it can be clearly seen the hydrological regime characteristics caused due to the climate conditions. Therefore, a climatological analysis is recommended to identify the future trends of the rainfall to the catchment and then, to forecast the future flow conditions.

The regulation degree was calculated to the mini hydropower plant. There is no reservoir to the mini hydropower station and the weir was used to divert the water to the head raised canal. However, the upstream of the stream was pounded due to this weir. Therefore, a small reservoir is automatically created upstream to the weir. The average flow to the mini hydropower plant is $11 \text{ m}^3/\text{s}$. Therefore, V_{flow} (annual flow volume)

Table 2 Resulting hydrological regime characteristics.

Flow characteristic	Alternation	Ecosystem response
Flow magnitude	Stabilized flow	Can contribute to failed establishment of riparian species and invasion of exotic species. There will be a dominance of competitive species and loss of poor competitors.
Flow frequency	No variation	No potential damage to the surrounding environment such as soil erosion or biodiversity threats.
Flood timing	Loss/change of seasonal flow variables	Disturbed life cycles that will lead to reduced growth rate and changed succession patterns. There will also be a reduced habitat availability.
Flow duration	Shortened low flows	Increases the availability of aquatic habitats.
	Shortened flood peaks	Encroachment of land organisms into the riverbed.
Rate of change of flow	Rapid changes in river stages	Loss of riparian zone and its vegetation. Failed establishment of riparian organisms because of wash out and stranding of organisms.

is 346 MCM/year (MCM = million cubic meters). Compared to this V_{flow} value, the storage above the weir is negligible. Therefore, the RD value should be less than 10 and the water system can be classified to Class 1. Therefore, Denawaka Ganga mini hydropower plant does not cause potential adverse effect to the environment in the sense of hydrological regime.

However, the sediment flow in original river in the stretch of intake weir to mini hydropower plant (roughly 2 km) is significantly blocked due to the head raised canal. The flow in that stretch is very low and therefore, the sediment flow is negligible. This makes adverse environmental effect on the surrounding and the aquatic life. However, sediment trapped in the screens of the head raised canal is released back to the downstream river. This helps to regain the nutrients flow from upstream to downstream.

Water quality tests were not carried out in this research. We believed the mini hydropower plant does not significantly involve in changing the water quality. This assumption was made as the Denawaka Ganga mini hydropower station is a non-reservoir type hydropower plant. Had it been incorporated with a reservoir, the water quality may be affected due to hydraulic retention time. However, there may be some oil and grease contamination due to the operation of roto-dynamic machines. Therefore, it is advisable to conduct some water quality analysis for oil and grease for the water release from the turbines.

However, the environmental impact value (EIV) was calculated for the Denawaka Ganga mini hydropower

plant. As it was stated earlier, EIV is one of the methods which can be used to indicate the potential impact caused to the environment. Table 3 gives the different weightages used in the three subsections (physical, biological and social environments). Furthermore, it shows the calculations for EIV .

Our field visit observations and discussions with the villages were helped in completing the EIV calculations. According to the summation of positive and negative impacts, Denawaka Ganga mini hydro power plant has reached to a value of -25. Hence by comparing the weight of positive impacts and the negative impacts, it can be concluded that there is a potential threat which can be caused by mini hydro power plants to the surrounding environment. The EIV results are presented in Fig. 5 for better understanding of impact on subsections.

Fig. 5 clearly presents the negative impacts of the mini hydropower plant for the physical and biological environment. The adverse impact on biological environment is quite significant. Therefore, as it was stated in the earlier section of the paper, a detailed biodiversity analysis is recommended. However, the mini hydropower plant has made a positive impact to the physical environment and social environment. Re-forestation and recycling of waste to generate compost were two of the important positive impacts from the mini hydropower plant.

The positive impacts of social environment were found from the discussions among the villages. Construction of several concrete roads (previously

these roads were either muddy roads without proper cover), construction of causeway across Denawaka Ganga, renovation of religious centers and community

halls in the area were few of the other identified positive social impacts of the Devaka Ganga mini hydropower project.

Table 3 EIV calculations.

Impact	V_i	W_i	V_iW_i
Physical environment			
Micro-climate and air quality	0	3	0
Change of flow characteristics	1	3	3 (-ve)
Topography and land use	2	2	4 (-ve)
Surface erosion	1	2	2 (-ve)
Disposal of excavated material	1	2	2 (-ve)
Hydrology and sedimentations	0	2	0
Water quality/pollution	0	4	0
Solid waste	0	3	0
Re-forestation	2	3	6 (+ve)
Composting and recycling	2	2	4 (+ve)
Noise and vibration	2	2	4 (-ve)
Biological environment			
Loss of forest cover	1	3	3 (-ve)
Increase in felling trees	1	2	2 (-ve)
Exploitation of non-timber forest products	2	2	4 (-ve)
Impact on biodiversity	3	3	9 (-ve)
Impact on rare endangered and threatened species	3	3	9 (-ve)
Impact on fish migration	1	2	2 (-ve)
Effect on riparian habitat	1	2	2 (-ve)
Downstream effect	0	1	0
Social environment			
Impacts in agricultural land	0	2	0
Women and child labour	0	2	0
Culture and religion	1	1	1 (-ve)
Public health	1	3	3 (-ve)
Occupational health and safety	0	4	0
Law and order	1	3	3 (-ve)
Impact on local life style	1	1	1 (-ve)
Increase pressure on local services	0	1	0
Increased local employment	3	2	6 (+ve)
Increase in local trade	3	2	6 (+ve)
Improvement in road condition	3	1	3 (+ve)
Rural electrification	4	2	8 (+ve)
Industrialization	2	2	4 (+ve)
Promotion in eco-tourism	1	2	2 (+ve)

Note: +ve: positive; -ve: negative.

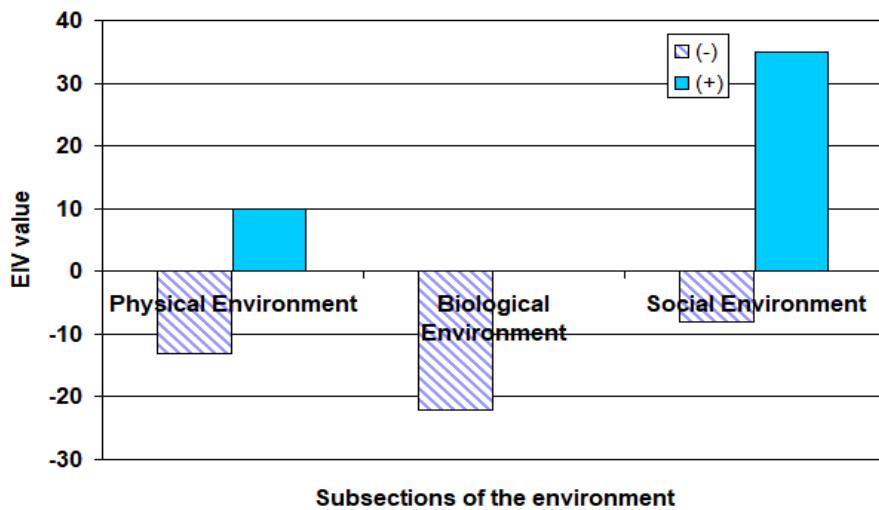


Fig. 5 EIVs for subsections of the environment.

6. Conclusions

A well functioned mini hydropower plant in Sri Lanka was selected as a case study to present the potential social and environmental impacts from a mini hydropower plant. The study shows some critical concerns on the environment; however, the positive gain to the society is significant. Therefore, Denawaka Ganga mini hydropower plant is an asset to the country. However, it is proposed to conduct future research to identify the rectification methods to bring the negative impacts to a much lower level. This includes conducting a water quality analysis and a biodiversity analysis. In addition, it is recommended to use *EIV* and *RD* values to assess the other mini-hydropower plants in the country. Based on the assessment, authorities can re-think on continuation of mini-hydropower plants if they score significant negative *EIV* scores. At the same time, if the assessed mini-hydropower plant has positive scores or insignificant negative values in *EIV*, they should be rewarded.

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References

- [1] Kjærland, F. 2007. "A Real Option Analysis of Investments in Hydropower—The Case of Norway." *Energy Policy* 35 (11): 5901-8.
- [2] Chang, X., Liu, X., and Zhou, W. 2010. "Hydropower in China at Present and Its Further Development." *Energy* 35 (11): 4400-6.
- [3] Kumar, A., Kumar, K., Kaushik, N., Sharma, S., and Mishra, S. 2010. "Renewable Energy in India: Current Status and Future Potentials." *Renewable and Sustainable Energy Reviews* 14 (8): 2434-42.
- [4] Evans, A., Strezov, V., and Evans, T. 2009. "Assessment of Sustainability Indicators for Renewable Energy Technologies." *Renewable and Sustainable Energy Reviews* 13 (5): 1082-8.
- [5] Paish, O. 2002. "Small Hydro Power: Technology and Current Status." *Renewable and Sustainable Energy Reviews* 6 (6): 537-56.
- [6] Sims, R., Rogner, H., and Gregory, K. 2003. "Carbon Emission and Mitigation Cost Comparisons between Fossil Fuel, Nuclear and Renewable Energy Resources for Electricity Generation." *Energy Policy* 31 (13): 1315-26.
- [7] Jager, H., and Smith, B. 2008. "Sustainable Reservoir Operation: Can We Generate Hydropower and Preserve Ecosystem Values?." *River Research and Applications* 24 (3): 340-52.
- [8] Rahman Mohamed, A., and Lee, K. 2006. "Energy for Sustainable Development in Malaysia: Energy Policy and Alternative Energy." *Energy Policy* 34 (15): 2388-97.
- [9] Yuksel, I. 2010. "As a Renewable Energy Hydropower for Sustainable Development in Turkey." *Renewable and Sustainable Energy Reviews* 14 (9): 3213-9.

[10] Yüksel, I. 2010. "Hydropower for Sustainable Water and Energy Development." *Renewable and Sustainable Energy Reviews* 14 (1): 462-9.

[11] Bayazit, Y., Bakış, R., and Koç, C. 2017. "An Investigation of Small Scale Hydropower Plants Using the Geographic Information System." *Renewable and Sustainable Energy Reviews* 67: 289-94.

[12] Bousquet, C., Samora, I., Manso, P., Rossi, L., Heller, P., and Schleiss, A. 2017. "Assessment of Hydropower Potential in Wastewater Systems and Application to Switzerland." *Renewable Energy* 113: 64-73.

[13] Hermoso, V. 2017. "Freshwater Ecosystems Could Become the Biggest Losers of the Paris Agreement." *Global Change Biology* 23 (9): 3433-6.

[14] Hoes, O., Meijer, L., Van der Ent, R., and Van de Giesen, N. 2017. "Systematic High-Resolution Assessment of Global Hydropower Potential." *PLOS ONE* 12 (2): 1-10.

[15] Manzano-Agugliaro, F., Taher, M., Zapata-Sierra, A., Juaidi, A., and Montoya, F. 2017. "An Overview of Research and Energy Evolution for Small Hydropower in Europe." *Renewable and Sustainable Energy Reviews* 75: 476-89.

[16] Nastase, G., Șerban, A., Năstase, A., and Iordan, N. 2017. "Hydropower Development in Romania. A Review from Its Beginnings to the Present." *Renewable and Sustainable Energy Reviews* 80: 297-312.

[17] Rojanamon, P., Chaisomphob, T., and Bureekul, T. 2009. "Application of Geographical Information System to Site Selection of Small Run-of-River Hydropower Project by Considering Engineering/Economic/Environmental Criteria and Social Impact." *Renewable and Sustainable Energy Reviews* 13 (9): 2336-48.

[18] Williams, A., and Porter, S. 2006. "Comparison of Hydropower Options for Developing Countries with Regard to the Environmental, Social and Economic Aspects." In *Proceedings of the International Conference on Renewable Energy for Developing Countries*, 1-17.

[19] Demirbas, A. 2005. "Potential Applications of Renewable Energy Sources, Biomass Combustion Problems in Boiler Power Systems and Combustion Related Environmental Issues." *Progress in Energy and Combustion Science* 31 (2): 171-92. doi:10.1016/j.pecs.2005.02.002.

[20] Bracken, L., Bulkeley, H., and Maynard, C. 2014. "Micro-hydro Power in the UK: The Role of Communities in an Emerging Energy Resource." *Energy Policy* 68: 92-101.

[21] Morales, S., Álvarez, C., Acevedo, C., Diaz, C., Rodriguez, M., and Pacheco, L. 2015. "An Overview of Small Hydropower Plants in Colombia: Status, Potential, Barriers and Perspectives." *Renewable and Sustainable Energy Reviews* 50: 1650-7.

[22] Sample, J., Duncan, N., Ferguson, M., and Cooksley, S. 2015. "Scotland's Hydropower: Current Capacity, Future Potential and the Possible Impacts of Climate Change." *Renewable and Sustainable Energy Reviews* 52: 111-22.

[23] Wagner, B., Hauer, C., Schoder, A., and Habersack, H. 2015. "A Review of Hydropower in Austria: Past, Present and Future Development." *Renewable and Sustainable Energy Reviews* 50: 304-14.

[24] Eriyagama, N., Smakhtin, V., and Jinapala, K. 2016. "The Sri Lanka Environmental Flow Calculator: A Science-Based Tool to Support Sustainable National Water Management." *Water Policy* 18 (2): 480-92.

[25] Fernando, S. 2002. "An Assessment of the Small Hydro Potential in Sri Lanka." *Energy for Sustainable Development* 6 (1): 95-8.

[26] Morimoto, R., and Munasinghe, M. 2005. "Small Hydropower Projects and Sustainable Energy Development in Sri Lanka." *International Journal of Global Energy Issues* 24 (1/2): 3.

[27] Anderson, D., Moggridge, H., Warren, P., and Shucksmith, J. 2014. "The Impacts of 'Run-of-River' Hydropower on the Physical and Ecological Condition of Rivers." *Water and Environment Journal* 29 (2): 268-76.

[28] Winemiller, K., McIntyre, P., Castello, L., Fluet-Chouinard, E., Giarrizzo, T., Nam, S., Baird, I., Darwall, W., Lujan, N., Harrison, I., Stiassny, M., Silvano, R., Fitzgerald, D., Pelicice, F., Agostinho, A., Gomes, L., Albert, J., Baran, E., Petrere, M., Zarfl, C., Mulligan, M., Sullivan, J., Arantes, C., Sousa, L., Koning, A., Hoeinghaus, D., Sabaj, M., Lundberg, J., Armbruster, J., Thieme, M., Petry, P., Zuanon, J., Vilara, G., Snoeks, J., Ou, C., Rainboth, W., Pavanelli, C., Akama, A., Soesbergen, A., and Saenz, L. 2016. "Balancing Hydropower and Biodiversity in the Amazon, Congo, and Mekong." *Science* 351 (62-69): 128-9.

[29] Yah, N., Oumer, A., and Idris, M. 2017. "Small Scale Hydro-Power as a Source of Renewable Energy in Malaysia: A Review." *Renewable and Sustainable Energy Reviews* 72: 228-39.

[30] Adam, N., Erpicum, S., Archambeau, P., Pirotton, M., and Dewals, B. 2014. "Stochastic Modelling of Reservoir Sedimentation in a Semi-arid Watershed." *Water Resources Management* 29 (3): 785-800.

[31] Weerakoon, S. B., and Rathnayake, U. S. 2007. "Effect of the Entrance Zone on the Trapping Efficiency of Desilting Tanks in Run-of-River Hydropower Plants." In *International Conference on Small Hydropower-Hydro Sri Lanka*, 22-4.

[32] Abbasi, T., and Abbasi, S. 2011. "Small Hydro and the Environmental Implications of Its Extensive Utilization." *Renewable and Sustainable Energy Reviews* 15 (4): 2134-43.

[33] Gracey, E., and Verones, F. 2016. "Impacts from hydropower production on biodiversity in an LCA framework—review and recommendations." *The International Journal of Life Cycle Assessment* 21(3): 412-28.

[34] Steinmetz, M., and Sundqvist, N. 2014. "Environmental Impacts of Small Hydropower Plants—A Case Study of Borås Energi och Miljö's Hydropower Plants." Master of Science thesis, Chalmers University of Technology.

[35] Arheimer, B., Donnelly, C., and Lindström, G. 2017. "Regulation of Snow-Fed Rivers Affects Flow Regimes More than Climate Change." *Nature Communications* 8 (1): 1-9.

[36] Gao, G., Li, T., Liu, Z., and Li, X. 2013. "Advances and Prospects of Reservoir Sedimentation Problem on Sediment-Laden River." *Applied Mechanics and Materials* 405-408: 2104-14.

[37] Tongal, H., and Berndtsson, R. 2016. "Impact of Complexity on Daily and Multi-step Forecasting of Streamflow with Chaotic, Stochastic, and Black-Box Models." *Stochastic Environmental Research and Risk Assessment* 31 (3): 661-82.

[38] Zhang, R., Chen, X., Zhang, Z., and Shi, P. 2014. "Evolution of Hydrological Drought under the Regulation of Two Reservoirs in the Headwater Basin of the Huaihe River, China." *Stochastic Environmental Research and Risk Assessment* 29 (2): 487-99.

[39] Zhangzhong, L., Yang, P., Ren, S., Liu, Y., and Li, Y. 2015. "Flow Characteristics and Pressure-Compensating Mechanism of Non-pressure-Compensating Drip Irrigation Emitters." *Irrigation and Drainage* 64 (5): 637-46.

[40] Coelho, A., and De Brito, J. 2012. "Influence of Construction and Demolition Waste Management on the Environmental Impact of Buildings." *Waste Management* 32 (3): 532-41.

[41] Huisman, J., Boks, C., and Stevles, A. 2003. "Quotes for Environmentally Weighted Recyclability (QWERTY): Concept of Describing Product Recyclability in Terms of Environmental Value." *International Journal of Production Research* 41 (16): 3649-65.

[42] Lu, L., Wernick, I., Hsiao, T., Yu, Y., Yang, Y., and Ma, H. 2006. "Balancing the Life Cycle Impacts of Notebook Computers: Taiwan's Experience." *Resources Conservation and Recycling* 48 (1): 13-25.

[43] Rydh, C. 1999. "Environmental Assessment of Vanadium Redox and Lead-Acid Batteries for Stationary Energy Storage." *Journal of Power Sources* 80 (1-2): 21-9.

[44] Safont, E., Vegas-Vilarúa, T., and Rull, V. 2012. Use of Environmental Impact Assessment (EIA) Tools to Set Priorities and Optimize Strategies in Biodiversity Conservation." *Biological Conservation* 149 (1): 113-21.

[45] Wijayatunga, P. 2014. "Regulation for Renewable Energy Development: Lessons from Sri Lanka Experience." *Renewable Energy* 61: 29-32.

[46] Punyawardena, B., and Cherry, N. 1999. "Assessment of the Predictability of Seasonal Rainfall in Ratnapura Using the Southern Oscillation and Its Two Extremes." *Journal of the National Science Foundation of Sri Lanka* 27 (3): 187-95.

[47] Churchill, R., and Hutchinson, D. 1984. "Flood Hazard in Ratnapura, Sri Lanka: Individual Attitudes vs. Collective Action." *Geoforum* 15 (4): 517-24.

[48] Eriyagama, N., Thilakarathne, M., Tharuka, P., Munaweera, T., Muthuwatta, L., Smakhtin, V., Premachandra, W., Pindeniya, D., Wijayarathne, N., and Udamulla, L. 2017. "Actual and Perceived Causes of Flood Risk: Climate versus Anthropogenic Effects in a Wet Zone Catchment in Sri Lanka." *Water International* 42 (7): 874-92.

[49] Nandalal, K. 2009. "Use of a Hydrodynamic Model to Forecast Floods of Kalu River in Sri Lanka." *Journal of Flood Risk Management* 2 (3): 151-8.

[50] MOE 2012. "The National Red List 2012 of Sri Lanka; Conservation Status of the Fauna and Flora." *Ministry of Environment, Colombo, Sri Lanka*. 7: 476

[51] Bergkamp, G., McCartney, M., Dugan, P., McNeely, J., Acreman, M. 2000. "Dams, Ecosystem Functions and Environmental Restoration: Thematic Review II." *I World Commission on Dams*, Cape Town, South Africa

[52] Renafalt, B., Jansson, R., and Nilsson, C. 2010. "Effects of Hydropower Generation and Opportunities for Environmental Flow Management in Swedish Riverine Ecosystems." *Freshwater Biology* 55 (1): 49-67.