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Generation of Construction Waste in Hydroelectric Power Station in Nepal

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Abstract: The purpose of this study is to investigate the estimated waste generation rate (WGR), the source of waste generation, and methods of waste management in a hydroelectric project in Nepal. The research had the following methods applied: analysis, synthesis, abstract-logical, questionnaire survey, and method of assessing the level of waste. The sources of waste generation were characterized and the methods of waste management in this context were considered. The influence of the lack of site management control and the error of the order in the disposal of waste were determined. It was found that the sale of cut metal and iron bars to scrap metal dealers was the most preferred method of waste management. The practical significance lies in providing constructive information for other hydropower project developers to achieve better planning and organisation of the waste management process.

Keywords: waste generation rate; waste management; waste factors; environmental impact; hydropower.

1. Introduction

Hydropower is a driver of sustainable growth. It helps to promote long-term growth that is good for the environment as well as the direct provider of firm electricity. Hydropower uses the potential energy of water to produce electricity, the most. In particular, this type of green energy produces 16%, which is the largest indicator among all developed forms of renewable energy[1].

Hydropower can be interoperable with other energy sources, such as solar and wind power. Hydropower development activities include building the major components of hydropower facilities. Such components include diversion structures (weirs or dams), water intake structures (pipes and tunnels), powerhouses, substations, switchyards, power transmission lines, and access roads. Waste occurs during different stages of the construction process and can be classified according to different criteria, such as the type of construction materials or the stage of the construction cycle. Construction waste (CW) management is important to reduce the negative impact on the environment. Possible approaches include the recovery and recycling of waste, the use of secondary raw materials, and the recycling of construction materials.

Waste quantification allows for effective and sustainable management of CW, which in turn leads to a reduction in the impact of the construction industry on the environment and the optimisation of resources[2]. A large number of studies have been conducted to estimate the amount of waste when designing various architectural solutions in different countries around the world. R. Islam et al. investigated the specifics of using indirect methods of measuring the level of waste generation (WGR) in the territory of Bangladesh[3]. Indirect measurement includes the compilation of the WGR based on the results of already-available research results and the calculation of the total amount of purchased construction materials. At the same time, direct measurements inherent in South Korea include hard and soft methods. Hard methods identify direct measurement by the researcher, while soft methods identify waste generated by questionnaires and measurements by contractors[4].

A study of the factors affecting waste generation rates in Thailand revealed that design documentation is the most favourable factor in the utilisation of CW, followed by the attitude and behaviour of workers, the use of different construction methods and planning, and finally materials and procurement[5]. In particular, China has the largest installed hydropower capacity in the world, accounting for more than 60% of national renewable energy production. The large number of hydropower projects implemented in recent decades is an important step in responding to climate change. However, the construction of such infrastructure facilities is accompanied by large carbon emissions associated with the consumption of energy-intensive materials[6-8].

The evaluation methodology is based on the Bayesian system derived from the theory of the value of information.

A concrete example of its use is the Smart Climate Hydropower Tool (SCHT), a climate service aimed at supporting management decisions in hydropower production. This service uses free seasonal forecasts and machine learning algorithms to predict discharge flows into hydroelectric reservoirs[9]. The user of the service is ENEL Green Power Italy, two tanks in Colombia were chosen for testing[10].

In Nepal, CW is considered a part of Municipal Solid Waste (MSW) and managed as MSW. According to a baseline survey of waste management in Nepal conducted by CBS, the total quantity of waste generated was 4619 kg/day. The total quantity of waste includes household waste, business waste, industrial waste, educational waste, hospital waste, and others. The CW is included in household waste[11]. And piling up in landfill sites was the main adopted method, while manure making was the lowest (Fig. 1).

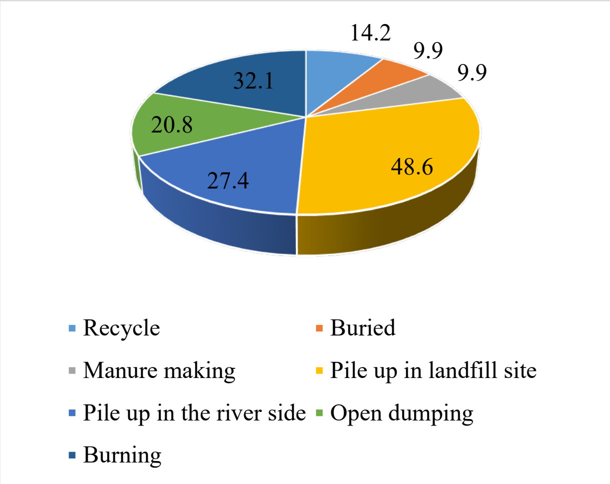

Fig. 1: Waste management practices in Nepal, 2020. Source: compiled by the authors based on Central Bureau of Statistics[12].

The low level of reporting on the number of landfills and the limited use of the opportunities of the recycling industry is a clear indication of the need for effective sanitary landfill management. Although the recycling process has received some recognition, its volume remains limited, representing only 4.1% of the total amount of waste collected. This indicates that considerable efforts for the identification of CW, its quantification, and waste management have not been made in Nepal[12]. There is also a lack of empirical studies indicating that environmental management deals with various issues, like waste management[13]. This approach to estimating the amount of CW generated and analysing the key factors contributing to its generation is critical for proper waste management. This requires detailed research and analysis to find out the amount of waste, its origin, and the main factors affecting its formation. Hence, this study has taken a specific Hydropower Project (HPP) to understand CW generation, identify the factors contributing to CW generation, its management practices, and the quantity of waste generated.

The purpose of this study is to substantiate methodological approaches to the risks of waste generation because of the engineering and construction processes and practical measures for the collection, management, and disposal of negative by-products using the example of a hydroelectric power plant located in Nepal.

2. Materials and Methods

One of the run-of-the-river type hydroelectric power stations with an installed capacity of 456 MW on the Tamakoshi River, around 200 kilometres from Kathmandu, Nepal was chosen as the research location. The Upper Tamakoshi Hydroelectric Project underwent construction work on June 30th, 2016 and was completed on July 8th, 2021[14]. The major project components are the dam, headrace tunnel (HRT), penstock pipe (PP), powerhouse (PH), and switchyard (SY). The total gross floor area occupied was 82636.76 m^2.

The research was carried out as per the post positivist worldview. The post-positivist assumptions hold true more for quantitative research. The study had a cross-sectional survey design. Survey research was used to quantitatively describe specific aspects of a given population. The research used field observation, measurement, and a questionnaire survey as a means of data collection.

Conducting field visits to the main research site every week for 6 months was a defining step to collect data on the waste generated and obtain a detailed characterization and analysis of waste dynamics over a long period of time. The area covered by the hydropower components was selected. It was calculated by using the properly scaled drawing. Materials used for the construction of different hydropower components were calculated by reviewing the Bill of Quantity (BoQ) prepared for the project.

Each project component, i.e., dam, headrace tunnel, penstock pipe, powerhouse, and switchyard, was visited, and waste dumped in those sites was sorted manually and classified by waste type as waste plastics, waste concrete (including cement and mortar), waste steel, waste iron, waste explosives, waste formwork (timber), waste tiles, waste chemicals/paints, waste fabrics, and waste packaging. Then, the generated waste was measured using a weighing machine. The waste that can be reused was separated, and the remaining waste was again measured.

The analysis of contractors' records, aimed at studying the amount and types of waste for each of the construction stages separately, is extremely important for the formation of the overall CW generation system. The described approach, with the breakdown of the total construction period into 10 stages, makes it possible to systematically investigate and compare the amount of waste at each stage to determine changes in waste generation.

The study used a carefully designed questionnaire to collect systematic and quantitative information on the sources of waste generation and waste management practices at construction sites in a hydropower project in Nepal. The questionnaire was developed based on a comprehensive literature review to ensure that all relevant aspects of construction waste management were covered[15]. Initially, the draft questionnaire was pre-tested in April 2021, after which necessary modifications were made. A full pilot test was then conducted among the 56 respondents to the project. The questionnaire was reviewed and validated by five experts to ensure validity. The reliability of the questionnaire was assessed using internal consistency measured by calculating the Cronbach's alpha coefficient, which ensured the reliability of the data collected[4].

The questionnaire structure included sections aimed at identifying sources of waste generation and current waste management practices. Respondents were asked to rate the severity and frequency of various factors contributing to waste generation using a Likert scale. This scale provides options ranging from "strongly" (5), "strongly" (4), "moderately" (3), "little" (2) and "none" (1) for severity, and "always" (5), "often" (4), "sometimes" (3), "rarely" (2) and "never" (1) for frequency. This structured approach allowed for the collection of detailed and in-depth data on factors affecting waste generation and disposal.

A total of 195 respondents out of 346 who were asked to answer the questions participated in the survey, representing a response rate of 56.35%. Respondents included project managers, engineers, geologists, environmental specialists, and semi-skilled and unskilled personnel. This wide range of participants ensured the completeness of the data collected and reflected different perspectives on the project.

The survey was open for 5 months, from July through the end of November 2021, giving respondents ample time to provide detailed and thoughtful responses. Analysis of the collected data included the calculation of severity and frequency indices to determine indices of the contribution of various factors to waste generation. In addition, a Relative Importance Index (RII) was calculated to rank statements related to current waste management practices (Table 1).

Table 1. Number of responses.

	No. of responses	**%**
Project coordinator	1	0.51
Project manager	1	0.51
Plant manager	1	0.51
Engineer	18	9.23
Geologist	1	0.51
Tunnel construction manger	1	0.51
Business manager	1	0.51
Environmental officer	1	0.51
Assistant environmental officer	4	2.05
Semi-skilled and unskilled workforce	166	85.13
Total	195	99.98

The study employed a comprehensive statistical analysis to evaluate the data collected through the questionnaire, providing a robust framework for understanding the sources of waste generation and the effectiveness of waste management practices at the hydropower project site in Nepal. A questionnaire survey was done to measure the opinion of project employers on the severity and frequencies of different factors towards the contribution to waste generation using the Likert scale[16]. WGR was calculated as the amount of net waste generated per unit area (kg/m^2). The following equation was used to determine the total amount of CW (1)[2]:

$$Q = \Sigma \rightarrow \Sigma\, A_i WGR_{jk}, \qquad (1)$$

where: Q – total volume of CW in the region; A_i – performance indicators of construction enterprises, measured in m^2; WGR_{jk} – rate of generation of waste of type JTH from the kth type of structure, expressed in the number of kg of waste per m^2.

The following formulas were used to derive the severity and frequency indices, as shown in O.O. Fadiya et al. (2, 3)[16]:

$$S_j = \Sigma_{W_j} X_i \qquad w_j = i/5 \qquad X_i = m_i/N, \qquad (2)$$

$$F_j = \Sigma_{W_j} Y_i\ d \qquad w_i = i/5\ d \quad Y_i = n_i/N, \qquad (3)$$

where: i – category in the rating system; w_j – weight factor of the selected category; i and j – primary and secondary factors affecting the amount of waste; m_i – representatives of the sample who voted for the degree of hazardous waste; n_i – representatives of the sample that counts the total number of all respondents; N – total number of survey results.

Respondents rated their responses to current waste management practices on a scale of 1 to 5, with 1 indicating the least importance and 5 the most important. The severity indices and factor indices were multiplied as applied by S.A. Assaf and S. Al-Hejji to determine contribution indices (C_j) and contribution indices were converted to rates to generate the percentages of contribution of different factors to waste generation (4)[17]:

$$\text{Rates} = C_j/\Sigma C_j * 100, \quad (4)$$

where: C_j – contribution indice.

The Relative Importance Index (RII) was used to identify the ranking of statements related to current waste management practices. The scores were transformed into important indices to determine the relative ranking of factors as per V.W.Y. Tam (5)[18]:

$$\text{RII} = \Sigma W/AN, \quad (5)$$

where: w – weighting of each factor by the respondent; A – largest weight possible for the assessment; the Relative Importance Index (RII) ranges from 0 to 1, where a higher value indicates a higher ranking.

This detailed statistical analysis provided a comprehensive understanding of the factors influencing waste generation and the effectiveness of current waste management practices, offering valuable insights for improving waste management strategies at construction sites in hydropower projects. To confirm the reliability of the obtained results and the reliability of the internal consistency of the multi-item scales, a Cronbach-alpha score was used for the severity and frequency of sources of construction debris. Cronbach's alpha is widely used to assess the reliability of Likert scales. The reliability coefficient ranges from 0 to 1, with a higher value indicating higher internal consistency of the scale[19].

3. Results

3.1 Total constructed waste generated

Specifically, nine different waste types were estimated: plastics, iron, steel, timber formwork, concrete, cement and mortar, fabric, explosives, tiles, and packaging materials. Table 2 shows the number of different types of Content Warnings.

Table 2. WGR and quantity of waste generated.

No.	Waste type	Before segregation			After segregation		
		WGR, kg/m^2	WGR, %	WG, ton	WGR, kg/m^2	WGR, %	WG, ton
1	Plastics	7.33	9.81	605.73	7.33	22.4	605.73
2	Iron	22.81	30.53	1884.94	2.81	8.59	232.21
3	Steel	18.47	24.72	1526.3	6.47	19.77	534.66
4	Timber formwork	11.13	14.9	919.75	1.13	3.45	93.38
5	Concrete, cement, mortar	8.11	10.85	670.18	8.11	24.79	670.18
6	Fabric	0.01	0.01	0.83	0.01	0.03	0.83
7	Explosives	0.48	0.64	39.67	0.48	1.47	39.67
8	Tiles	0.12	0.16	9.92	0.12	0.37	9.92
9	Others (packaging materials)	6.26	8.38	517.31	6.26	19.13	517.31
Total		74.72	100	6174.63	32.72	100	2703.89

The total amount of CW generated was 6174.62 ton. Waste iron made up the highest proportion (30.53%) followed by steel (24.72%). After the waste segregation, the waste that can be reused and recycled was deducted from the gross amount of CW generated, and hence the net amount of CW generated was found to be 2703.89 ton which is 56.21% less than the gross CW generated. WGR of waste iron, steel, and timber formwork was found to be decreased by 87.68%, 64.97% and 89.85% respectively[5]. Other wastes were not found to be segregated for reuse purposes. Fabric, tiles/slabs, and explosives made up the minor types of CW generated. Fabric was used on the dam site only, whereas explosives were found to be used on the dam site, and HRT, tiles, and slabs were used in PH construction only. Packaging materials like cardboard, paper, and polythene contribute more than fabric, tiles/slabs and explosives. Waste plastic includes waste plastic sheets, waste plastic pipes. Figure 2 shows waste data for different materials in each component of the project. Dam construction generates the largest amount of waste among all HPP components. Steel and iron were the major waste generated during the construction of HRT and PP.

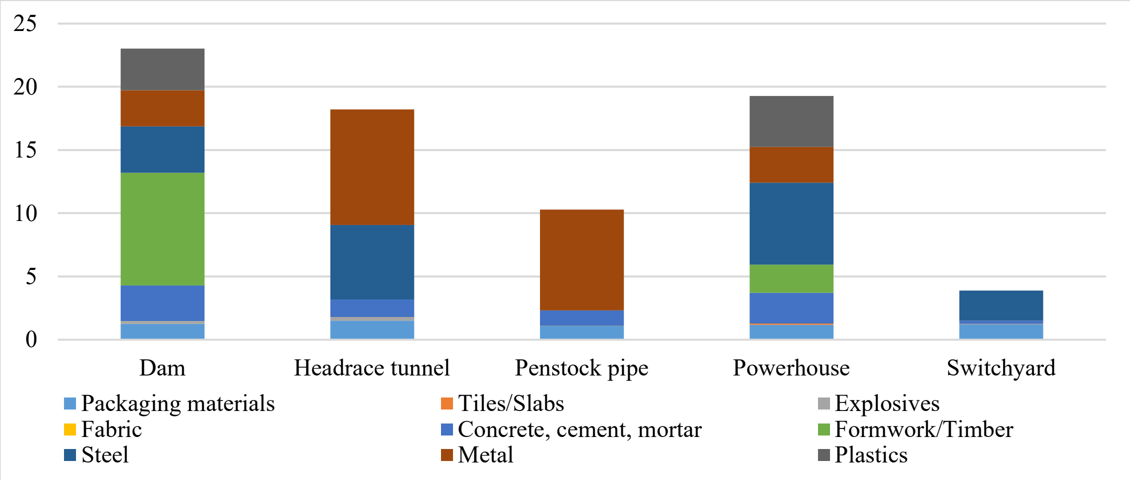

Fig. 2: Waste types generated in HPP Components.
Source: compiled by the authors.

Steel plays a critical part in HPP. Concrete is characterised by high compressive strength but is relatively weak in terms of twisting or stretching. In such cases, steel is used as an additional element. Steel rebar is embedded in the concrete to give it extra strength in bearing directions where the concrete may be less effective[20]. Penstock pipes are made of iron pipes and reinforced concrete. Similarly, shotcrete and rock bolts are used in HRT. Hence, steel dominates the waste type. Waste formwork was generated in the construction of the dam and powerhouse only.

3.2 CW category

The total amount of waste was analysed according to the European Waste Catalog Code (EWC Code) (Table 3)[21]. Thus, it was established that during the construction of hydroelectric power stations, the largest amount of waste, in particular 50% of the total mass of CW, is cast iron and steel (EWC code 17 04 05). In second place by volume was wood/timber (formwork) (EWC code 17 02 01). The least amount of waste was in the category "other construction and demolition waste" (EWC code 17 09 04):

- 17 01 07 (concrete, brick, facing tiles and ceramics);
- 17 04 05 (iron and steel);
- 15 01 06 (mixed packaging);
- 16 04 03 (other waste explosives);
- 17 02 01 (wood);
- 17 09 04 (other construction and demolition waste).

Table 3. Waste type generation according to EWC Code.

No.	EWC Code	Waste type	WG (ton)
1	17 04 05	Iron and steel	3411.24
2	17 02 03	Plastics	605.73
3	17 02 01	Wood	919.75
4	17 09 04	Other construction and demolition waste	0.83
5	17 01 07	Concrete, brick, facing tiles and ceramics	680.1
6	16 04 03	Other waste explosives	39.67
7	15 01 06	Mixed packaging	517.31

Source: compiled by the authors.

Recording of the total amount of hydrocarbon emissions generated during construction. At this stage of the research, various types of chemical emissions occurring at different stages of construction were characterized. Cumulative chemical emissions show a similar "S" curve shape as shown in Fig. 3 Except for waste explosives and waste tiles/slabs, all other waste types were generated throughout the construction period. The accumulated waste increased from beginning to end. Waste explosives were generated up to 80% completion of construction works, whereas waste tiles were generated after 50% completion of construction work to 90% completion stage. The waste generation increased until the project reached 80% progress. After that, waste generation slowed down. This indicates that the largest amount of chemical emissions is generated during the first half of construction or during its peak period.

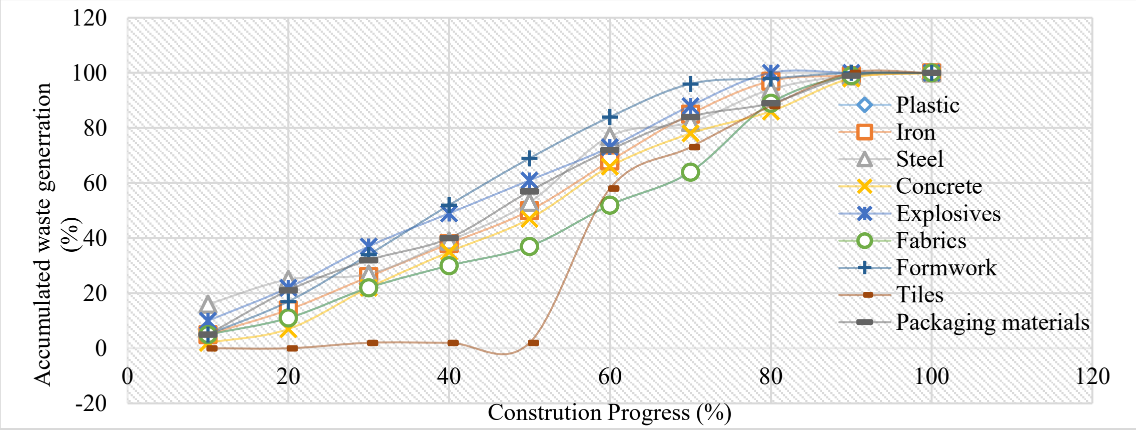

Fig. 3: Variation in CW generation during construction progress.
Source: compiled by the authors.

Figure 4 shows the amount of CW generated during the construction period. The maximum CW amount (18.62% of the total) was generated in the 51 to 60% of work progress, and the lowest CW amount (0.95% of the total) was generated at the end of the construction period (91 to 100%). It showed that the CW generation was low at the beginning, more in the middle of the construction stage, and then decreased and reached its minimum point at the final stage of construction. The generation of waste steel was higher at the beginning of the work, but it decreased until 30% of the work was completed.

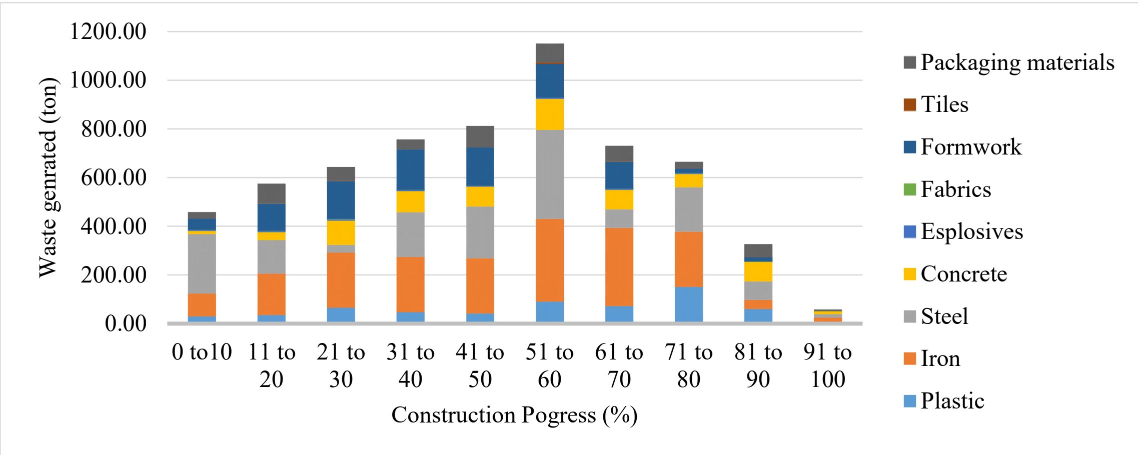

Fig. 4: Types and quantity of WG during the different stages of construction.
Source: compiled by the authors.

HPP requires different construction materials. The most severe factor responsible for CW generation was found to be residuals, followed by a lack of material storage sites and a management plan. CW due to vandalism was found to be the least severe factor (Table 4). In terms of frequency of contributing factors, ordering errors were ranked first, followed by a lack of material storage sites and a management plan (Table 5).

Table 4. Indexes for calculating the risks of CW generation.

Factors	Possible answers for each category					Severity indices (Si)
	X_1	X_2	X_3	X_4	X_5	
Purchases, such as ordering errors and supplier errors due to data inaccuracies (Q1)	0.2143	0.5179	0.2143	0.0536	0	0.4643
Design, e.g., design changes and errors in contract documents (Q2)	0.1964	0.5714	0.1071	0.125	0	0.4214
Operations such as technician errors and equipment failure (Q3)	0.0357	0.4821	0.2143	0.2679	0	0.4214
Damage caused by weather conditions such as temperature and humidity (Q4)	0.0714	0.4643	0.2321	0.2321	0	0.4036

Safety, e.g., damage on the construction site due to vandalism (question 5)	0.25	0.3571	0.1964	0.1964	0	0.4000
Residues such as off-cuts from cutting materials to length and packaging (Q6)	0.1071	0.4107	0.25	0.2321	0	0.7286
Others, such as a lack of on-site material control and waste management plans (Q7)	0.4107	0.375	0.1786	0.0357	0	0.55

Source: compiled by the authors.

Table 5. Frequency indices of the factors contributing to waste generation.

Factors	Probabilities for response categories					Frequency indices (F_j)
	Y_1	Y_2	Y_3	Y_4	Y_5	
Indicators of the procurement error index in relation to data inaccuracy (Q1)	0.0357	0.4821	0.2143	0.2679	0	0.5429
Errors in the technical design or in the cooperation agreement (Q2)	0.4107	0.375	0.1786	0.0357	0	0.3679
Index of reference equipment (technical inaccuracies in equipment design) when performing various operations (Q3)	0.2857	0.3214	0.1964	0.1964	0	0.4607
Data inaccuracy index due to natural and climatic conditions such as temperature and humidity (Q4)	0.1071	0.4107	0.25	0.2321	0	0.5214
Risk index during construction (Q5)	0.1964	0.5714	0.1071	0.125	0	0.4321
Waste from lumber and other remains of construction, repair, dismantling works (Q6)	0.2143	0.5179	0.2143	0.0536	0	0.4214
Calculation index regarding the lack of a control system for the necessary materials and waste disposal plans (Q7)	0.0714	0.4643	0.2321	0.2321	0	0.525

Source: compiled by the authors.

At the same time, it was found that the main factor contributing to the formation of chemical emissions are the pieces of materials of a certain length and their packaging, which become suitable for use. These segments occur when cutting materials with a contribution index of 0.307. This was due to the lack of control over materials at the site and the occurrence of unforeseen situations related to waste. In third place was the procurement error, with a value of C=0.252. Design error was the least contributing factor for CW generation (Table 6).

Table 6. Contribution indices of the factors contributing to waste generation sources.

Factors	S_i	F_j	C	Rate (%)	Rank
Q1	0.4643	0.5429	0.252	15.95	3
Q2	0.4214	0.3679	0.155	9.81	7
Q3	0.4214	0.4607	0.1942	12.29	5
Q4	0.4036	0.5214	0.2104	13.32	4
Q5	0.4	0.4321	0.1729	10.94	6
Q6	0.7286	0.4214	0.307	19.42	1
Q7	0.55	0.525	0.2888	18.27	2

Source: compiled by the authors.

The reliability of the data on the severity and frequency of factors contributing to waste generation was validated by Cronbach's alpha test of 0.707 and 0.712 respectively, indicating a high level of internal consistency. The Environmental Impact Assessment (EIA) of the hydropower project was conducted and approved by the then Ministry of Population and Environment. This environmental study has included the waste management plan[6)]. There is an Environmental Management Plan (EMP) in the study area, which is a system that includes elements, the main of which are the Waste Management Plan (WMP) and the plan for the use of excavated material. The project has hired a consultant for the implementation of EM[22)]. They have also coordinated with the local government for waste management and the provision of bins for different wastes before disposal. They have no provision for a specific area for waste sorting or waste collection. All types of CW are mixed and collected together. Partial implementation of the WMP showed a misalignment between the client, contractors, and environmental consultant[2)].

3.3 Waste management hierarchy

The findings showed a low level of waste management practices at the construction site (Table 7). Selling the waste, like metal scraps, was the most commonly practiced method on construction sites, as it was more economical than other practices. Scrap metal collectors collect metal waste, such as cut sheets and bars. The collection and further implementation of these materials is an effective way of promoting positive use and recycling outside the enterprise. The sale of the waste is followed by leave. Decomposable wastes like wood, packaging paper, and cement racks were found to be left on sites. These wastes are buried. Also, they are supposed to burn once construction is completed.

Table 7. Waste management hierarchy at construction sites.

Waste management practices	W	RII	Ranking
Sell	182	0.65	1
Leave/bury/burn	150	0.5357	2
Disposal	144	0.5143	3
Reuse	138	0.4929	4
Give others	122	0.4357	5
Recycle	113	0.4036	6
Cronbach's alpha for reliability test	0.762		

Source: compiled by the authors.

Excavated spoils, rocks and aggregates, concrete, bricks, and tiles were found to be dumped in the designated area. They use their own dump trucks to carry waste to the disposal site. All the projects have a designated area to dump excavated materials. Disposal sites are allocated in the EIA report. Areas of muck disposal sites were allocated on the basis of the estimated volume of excavated materials. Disposal sites were allocated on river banks. Once the muck and soil get dumped, they will be labelled and left for other purposes[23].

The project uses detonators and explosives for tunnelling purposes. The surplus explosives are handled by licensed personnel. According to Section 4 of the Explosives Act, production, storage, use, transportation, or import of explosives is permitted only with a license issued by the licensee[24]. If the license does not meet the conditions specified in it, such actions are unacceptable. Hence, the use and disposal of explosives, including detonators, are handled by the Nepal Army at all construction sites. A separate bunker was established for storing those explosives. The surplus and wastage of explosives are not disposed of by mixing with other CW. Detonators and explosive materials must be disposed of in accordance with the manufacturer's instructions and not by burning. The fourth waste management activity is the reuse of the waste. Materials like wood, plastic, and rubber are reused many times as much as possible to minimise the cost[25]. The last fifth and sixth rank of waste management are given to others and recycled. The contractors collect the remaining unused materials so that they can be used in similar projects. Recycling of the waste on-site is least preferred as it is costly[26]. Cronbach's alpha estimated for testing the reliability of the data on waste management practices was found to be 0.762 which falls within the generally acceptable range and shows that there is interrelatedness between the items.

4. Discussion

The rationale for this study is different from previous ones in terms of CW generation and typification. Most of the previous studies were carried out during the construction of apartments. Thus, their findings show that waste from artificial construction materials, in particular concrete mixes, has the greatest negative impact compared to the total percentage of emissions. In particular, concrete is the main building construction material, for example, the WGR for concrete is 17.7 kg/m^2, steel bar is 4 kg/m^2, and tile is 0.5 kg/m^2. This study showed that iron contributes the highest proportion of total CW generated. This is because iron constitutes the major construction material for the project. None of the researchers have mentioned the waste explosives, but the HPP construction generates the waste explosives. It is because explosives are used for blasting during the tunnel construction and other underground structures.

Some unusable pieces are produced when the construction materials are cut off. For example, while fitting the penstock pipes, some shorts of unusable pieces of metal are produced; unusable pieces of cable wires are produced while connecting the wires[5,27]. The general process of waste generation is affected by the carelessness of industry workers, in particular, inaccuracies when ordering the right material and supplying completely different raw materials. This is the third-determining factor affecting the entire production process. During the study, it was found that contractors often order an additional number of materials to avoid interruptions, as if the quantified number of materials may get damaged during material handling and transportation. In addition, the hydro-mechanical equipment is to be bought from neighbouring countries, India and China. There is an increase in the number of large-scale hydropower projects (HPP) in various countries. This is partly due to the increased interest in the use of renewable energy sources and the fight against climate change[10]. Hydropower, in particular large hydroelectric power plants, can serve as an effective source of “green” energy, reducing greenhouse gas emissions and ensuring stable energy production[28),29)]. These hydroelectric power plants can involve the construction of high dams that form large reservoirs and are used to generate electricity. However, alongside the environmental benefits, such projects can raise questions about environmental impact, loss of biodiversity, and impact on local communities. This shows the trend of developing hydropower projects in the efforts of many countries to make their energy production more sustainable and environmentally friendly[30)].

According to the research of E. Quaranta and S. Muntean, the combination of hydropower technologies with other energy sources attracts special attention[31)]. Innovative approaches to assessing the potential of using excess (and lost) energy sources at existing hydropower facilities in Europe were used in their research. At the same time, three sources of energy should be considered: the hydrokinetic energy of the water flow in the tail tract, the potential energy associated with the unused pressure below the Pelton blocks, and the thermal energy of the generator cooling system. Given the existing technologies, it is possible to produce 5 TWh of heat due to the thermal energy of the cooling systems. The hydrokinetic energy of the tailings tract can provide the generation of 2.4 TWh/year of electricity, which corresponds to thousands of micro-hydroelectric plants of 100 kW each and allows for the avoidance of the construction of new facilities in natural freshwater systems. Undoubtedly, the scientific work of the researchers includes various innovations, including the first continental assessment in this direction and the establishment of methodologies that can be used at the regional level. This study carried out a detailed literature review of each technology to collect data and examples and provided data to estimate the number of units and operating range of Francis, Kaplan and Pelton water turbines in Europe. An equation for estimating methane emissions during degassing is also provided. These data can be used for similar large-scale evaluations. The obtained research results indicate the importance of taking environmental costs into account when making decisions about the development of hydropower both in the United States and in other countries around the world, especially in connection with the limited scale of most of the remaining potential and increasing environmental requirements. Therefore, the development of technologies to reduce the environmental impact and costs of hydropower will be a key aspect of future projects in this field[32)]. It is also important to implement a system of permanent environmental monitoring to track the impact of hydropower projects on natural resources and the ecosystem[33)].

The full implementation of WMP is similar to the study conducted by H.R. Ghimire et al., which concludes that even though WMP is included in the Environmental Impact Assessment (EIA) document, it is not fully implemented in HPP of Nepal[34)]. Implementation and effectiveness of environmental studies are influenced by project proponents, and for them, the environment is not a topic of priority[35)]. Having only a limited number of suppliers can make it difficult to choose the optimal solution for the disposal of specific types of waste. And the low frequency of collection creates problems with serving the population and enterprises, increasing the risk of the spread of diseases and other hygiene problems, as noted by F. Nyumah et al.[36)]. The lack of consensus among all participants in the construction and waste disposal process can lead to the fact that different parties have different understandings of the standards and norms governing the implementation of environmental measures. It can lead to violations of environmental standards and regulations, which reduces the economic efficiency and legitimacy of the project[12);37)].

The most preferred method for waste management was found to be selling. Waste iron and steel bars are collected and resold to second-hand buyers. The project proponent expects to obtain a profit while selling to others[38)]. A high percentage of disposal in the open area may indicate ineffective or absent regulation and supervision of waste disposal, which may lead to non-compliance with environmental standards and regulations, as argued by F. Nyumah et al.[36)]. Effective waste management requires not only an appropriate infrastructure but also skilled workers who understand disposal technologies, safety rules, and the environmental aspects of this activity[39)]. Reuse of waste is less preferred than disposal, and recycling is the least preferred waste management method[40)]. The problem is related to contamination and the quality of waste. Lack of information related to the quantity of CW and difficulties in the collection, sorting, and transportation of waste for recycling are the dominant issues contributing to the low rate of recycling[41),42)].

In this way, waste disposal can help recover useful resources such as metals, polymers, or other materials that can be used again in production. Ensuring compliance with environmental and sanitary standards will contribute to energy production in an ecologically clean environment and compliance with relevant legislative requirements. The implementation of the latest waste disposal technologies in hydropower projects contributes to the development of innovative solutions and supports technological progress in this field[43),44)].

The study on waste management in a hydroelectric project in Nepal highlights the significant waste generated during construction, particularly iron and steel. Effective waste management is crucial to minimize environmental impact. The research suggests that better planning, ordering accuracy, and site management can significantly reduce waste. Selling surplus materials is the most common waste management practice, while recycling is the least preferred due to contamination and quality issues. However, the study has limitations, such as being limited to a single hydroelectric project and not exploring socio-economic factors influencing waste management practices. Future research should include a larger sample size, qualitative methods, and the integration of advanced technologies like smart waste tracking and automated sorting systems. Policymakers and practitioners should consider these findings when developing more effective waste management strategies.

5. Conclusions

The present study identifies the primary contributors to waste generation in a hydroelectric project in Nepal, highlighting residuals (off-cuts of material), lack of site management control, and ordering errors as the first, second, and third major factors. On the basis of direct measurement and review of the contractor's records, the study estimated WGR to be 74.72 kg/m². Iron represents the highest WGR at 30.53%, followed by steel at 24.72% and timber formwork at 14.9%, with fabric having the smallest WGR at 0.01%.

The research reveals that the most effective waste management methods are selling surplus and unused materials, leaving waste on-site, and disposing of it in designated areas. These findings show that waste management practices at construction sites are at a low level. Effective management of generated explosives is essential for establishing an environmentally safe system for the collection, processing, and disposal of waste. The insights from this research are crucial for HPP companies to enhance planning and organising their waste management processes. To obtain more representative values of CW generation, further research involving multiple HPPs is recommended.

The study emphasises the need for developing and implementing effective CW management systems at construction sites, encompassing the collection, sorting, processing, and utilisation of waste. Additionally, the research suggests exploring the use of green construction technologies to minimise environmental impacts and CW generation, developing new materials and construction technologies that reduce waste, and assessing the social and environmental impacts of CW on local communities. This comprehensive approach is vital for creating strategies to mitigate the adverse effects of CW generation.

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