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Research Article

Development of a system-multi criteria analysis on erosion and sediment control in construction industry

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Abstract

Background: The construction industry faces erosion and sediment control (ESC) as its main environmental problem because urban areas of the United States experience fast population growth. The natural soil structure faces disruption during construction work which leads to elevated risks of water erosion that carries sediment particles which then harm both water quality and drainage systems and environmental balance. **Methods:** The research establishes a system-based Multi-Criteria Decision Analysis (MCDA) framework which evaluates different ESC practices. The research team distributed structured questionnaires to 175 construction industry workers who included engineers and contractors and project managers and environmental consultants based in the USA. The research team used descriptive statistics together with reliability testing (Cronbach's Alpha) and correlation analysis and weighted MCDA techniques to analyze the data. **Results:** The research shows that storm water Management functions as the leading factor with a mean score of 4.41 followed by Regulatory Compliance which scored 4.35 and Site Stability received 4.29. The reliability measurements showed values between 0.79 and 0.88 which proved the instrument maintained strong consistency between its elements. The correlation analysis revealed that all variables maintained strong connections with each other while storm water Management and Site Stability showed the strongest connection at r = 0.73. **Conclusion:** ESC performance in American construction sector depends most on environmental factors and regulatory requirements instead of financial elements. MCDA framework solution provides a functional decision-support system which helps sustainable construction practices move forward while decreasing their negative impact on the environment.

Keywords

Construction Industry; storm water Management; Environmental Sustainability; Erosion and Sediment Control; Multi-Criteria Decision Analysis;

1. Introduction

The construction industry faces a major environmental problem because of erosion and sediment control (ESC) which impacts fast-growing nations including the United States. The process of construction work which involves land clearing and excavation and grading and infrastructure building creates major disruptions to the natural arrangement of soil layers (Al-Ani et al., 2016). The exposed soils become defenseless against rainwater which creates surface water flow that strengthens erosion while carrying away sediment particles (Moore et al., 2017). These sediments flow into adjacent rivers and drainage systems and ecological habitats which results in extensive environmental harm. Construction site sediment runoff stands as a primary factor which leads to non-point source pollution in water bodies (Azimi et al., 2022). The water becomes worse because particles float in the water which stops sunlight from reaching the water and

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breaks down natural habitats in aquatic environments (Sadeghiravesh et al., 2023). Accumulation of sediment in drainage networks results in blockages which make urban areas more vulnerable to flooding and damage to their infrastructure. The environmental effects create two major problems because they harm nature while making cities and building companies pay more money for extended periods (Ren et al., 2017; Chapman et al., 2014).

Environmental Protection Agency (EPA) together with other regulatory bodies have created specific guidelines to control storm water and prevent erosion from happening (Tao et al., 2021). The regulations demand construction sites to establish ESC systems which include silt fences and sediment basins and erosion control blankets and check dams and mulching and vegetation-based stabilization methods (Zhu et al., 2016). These measures depend on various factors which include site conditions and maintenance routines and contractor abilities and monitoring effectiveness. Environmental management depends more on structured analytical methods for decision-making during the past few years (Gao et al., 2019). Multi-Criteria Decision Analysis (MCDA) method provides an effective solution for handling complicated problems which involve multiple connected elements. Organizations use MCDA to establish criteria weights which they employ to compare different options through their weighted average calculation (Xu et al., 2021). ESC research method combines environmental performance data with regulatory compliance information and technical system stability results and workforce capability assessments and cost analysis into one complete system (Ahmed et al., 2023).

The current research about ESC lacks system-based evaluation because it uses construction professional data instead of real-world evidence. The majority of research concentrates on individual methods and their effects on specific environmental areas instead of developing complete decision frameworks. The study establishes a system-based MCDA framework which serves to determine ESC practice performance across construction operations in the United States. The analysis depends on construction professional perceptions to determine which elements most strongly affect ESC operational success. The study shows that storm water management produces about 26% of total ESC success which makes it the primary factor when we analyze all the variables. The evidence demonstrates that runoff control systems and drainage systems serve as primary methods to decrease soil erosion which happens during construction activities.

2. Materials and Methods

2.1 Research Design and Framework

This study utilized a quantitative cross-sectional survey approach to assess the United States construction industry handles erosion and sediment control (ESC) practices. This design because it allows them to study construction and environmental management professional beliefs during their work activities (Wu et al., 2016). The framework incorporates environmental elements together with technical aspects and managerial components and economic factors to create a complete analytical system. A structured questionnaire through their review of established ESC literature and their examination of industry guidelines (Liu et al., 2016). The study evaluated five essential components which included storm water Management and Regulatory Compliance and Site Stability and Training & Monitoring and Cost Efficiency (Tsitsis et al., 2023). The five-point Likert scale helped researchers measure responses which ranged from strongly disagree to strongly agree. The method produces organized data which contains identical information that statistical tools can process to show ESC performance elements in various American construction environments (Ahmed et al., 2021).

2.2 Data Collection and Sampling Strategy

The research team collected primary data from 175 construction experts who operated throughout different parts of the United States. Information from civil engineers and project managers and contractors and environmental consultants and site supervisors and regulatory personnel. We used purposive sampling to select participants who possessed experience in erosion and sediment control practices. Distributed an online survey which people completed after receiving it through their professional networks and industry-based connections (Ali et al., 2020). The study allowed participants to join freely while keeping their identities hidden to obtain dependable answers without any influence. Statistical analysis through correlation and MCDA methods. The research findings receive validation from various professional groups which enables accurate assessment of construction sector ESC implementation methods (Rowe et al., 2015).

2.3 Variables and Measurement Design

The research examined five essential variables which included storm water Management (SM) and Regulatory Compliance (RC) and Site Stability (SS) and Training & Monitoring (TM) and Cost Efficiency (CE) for erosion and sediment control (ESC) systems (Cudahy, 2016; Upton & MacDonald, 2021). The research team selected these constructs after they reviewed earlier studies and followed industry standards for best practices. The research team gathered data for each variable through multiple measurement

indicators which assessed both technical aspects and managerial factors of ESC system performance (Sandlin et al., 2020). A five-point Likert scale was used, where 1 indicates strongly disagree and 5 indicates strongly agree. The evaluation system enables users to convert their personal experiences into numerical values which scientists can use for statistical studies (Blanchard et al., 2017). The variables represent different domains which include environmental effectiveness and regulatory influence and structural stability and human resource capability and economic efficiency. The measurement framework allows construction projects to evaluate their ESC implementation through an all-encompassing assessment system (Lange et al., 2012).

2.4 Data Analysis Techniques

We used SPSS software to analyze data which ensured both accurate results and consistent evaluation of all data points. Descriptive statistical analysis to calculate average values and variation measures and identify the lowest and highest values which summarized how respondents viewed the situation. Reliability analysis through Cronbach's Alpha to determine how well the measurement scale elements worked together as a single unit (Libert & Lipponen, 2012). Pearson correlation analysis to study how ESC variables connected with each other and to detect system-based interrelationships between these variables (Olsson et al., 2012; Bemelmans et al., 2023). Finally, Multi-Criteria Decision Analysis (MCDA) was used to prioritize ESC factors based on relative importance. Weighted scores were calculated using

$WS = \Sigma (wi \times xi)$

where wi represents variable weight and xi represents mean score. This combined statistical and decision-analytic approach provides a robust framework for evaluating ESC performance and supports evidence-based decision-making in sustainable construction management.

3. Results

3.1 Descriptive Statistics of Major Variables

In **Table 1** presents the descriptive statistics which show all essential erosion and sediment control (ESC) variables that operate in USA construction industry. The data reveals that Storm Water Management (SM) received the highest average score of 4.41 which proves its essential function for controlling soil erosion and sediment transport during runoff events. Regulatory Compliance (RC) and Site Stability (SS) obtained average scores of 4.35 and 4.29 which prove that environmental rules and slope protection methods have become vital for sustainable construction management. Monitoring (TM) reached a positive average score of 4.12 which proves that skilled supervision together with ongoing monitoring activities lead to better ESC results. The data shows that Cost Efficiency (CE) received the lowest average score of 3.98 which proves economic constraints create a moderate barrier for implementing this practice.

Table 1. *Descriptive Statistics of ESC Variables*

Variables	Mean	Std. Deviation	Minimum	Maximum
Regulatory Compliance (RC)	4.35	0.63	2.10	5.00
Cost Efficiency (CE)	3.98	0.72	1.90	5.00
Storm water Management (SM)	4.41	0.58	2.45	5.00
Site Stability (SS)	4.29	0.61	2.30	5.00
Training & Monitoring (TM)	4.12	0.67	2.00	5.00

3.2 Reliability Analysis

The research data in **Table 2** display reliability statistics which Cronbach's Alpha uses to measure how well the questionnaire items maintain their internal consistency. The research data showed alpha values which ranged between 0.79 and 0.88 to demonstrate strong reliability for every construct under investigation. Storm Water Management (SM) system showed the best reliability score of 0.88 because respondents provided identical answers about their methods for handling runoff and sediment control. Instruments which measured Regulatory Compliance (RC) and Site Stability (SS) showed strong reliability through alpha scores of 0.86 and 0.84 which proved their effectiveness in assessing environmental and technical management elements. Cost Efficiency (CE) achieved a reliability score of 0.81 which met the required standards. Monitoring (TM) variable reached the lowest acceptable reliability score through its alpha value of 0.79. The study results demonstrated that the survey instrument achieved statistical reliability which made it appropriate for upcoming multi-criteria and correlation studies in the research.

Table 2. *Reliability Statistics*

Construct	No. of Items	Cronbach's Alpha
Regulatory Compliance	5	0.86
Cost Efficiency	4	0.81
Storm water Management	5	0.88
Site Stability	4	0.84
Training & Monitoring	4	0.79

3.3 Correlation Matrix among ESC Variables

Correlation matrix in **Figure 1** reveals strong positive relationships among all erosion and sediment control (ESC) variables, indicating strong interdependence within the system. The data shows that Storm Water Management (SM) has the strongest link to Site Stability (SS) because of a 0.73 correlation which proves that proper runoff management leads to better slope stability and lower erosion potential. The data shows that Regulatory Compliance (RC) has strong connections to SM (r = 0.71) and SS (r = 0.66) which indicates that enforced environmental rules lead to better ESC measure technical execution. The data shows that Training & Monitoring (TM) forms strong connections with RC (0.62), SM (0.69), and SS (0.65) which proves that employee knowledge and monitoring systems lead to better work results. The data reveals that Cost Efficiency (CE) creates weak links to other variables but it establishes positive connections with every variable in the analysis.

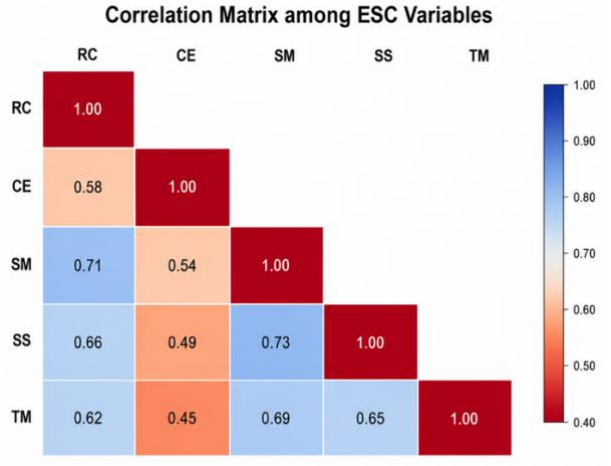

Figure 1. *Correlation Matrix among ESC Variables*

3.4 Weighted Multi-Criteria Decision Analysis (MCDA)

Weighted Multi-Criteria Decision Analysis (MCDA) which shows how erosion and sediment control (ESC) elements affect construction projects throughout the United States as **Table 3**. Storm water Management (SM) stands as the most important criterion because it holds the top weight of 0.27 and produces the highest weighted score of 1.19 which results in a "Very High" priority level because of its vital function to control water runoff and sediment movement. Regulatory Compliance (RC) maintains a weight of 0.24 and score of 1.04 which earns it a "Very High" ranking that demonstrates how environmental laws and their enforcement systems produce major effects. The Site Stability (SS) category receives a "High" priority rating of 0.90 because it performs vital functions which protect slopes and prevent erosion. Training & Monitoring (TM) and Cost Efficiency (CE) are categorized as "Moderate," indicating supportive but secondary roles in ESC effectiveness.

Table 3. *Weighted Multi-Criteria Decision Analysis (MCDA)*

Criteria	Weight	Mean Score	Weighted Score	Priority Level
Storm water Management	0.27	4.41	1.19	Very High
Regulatory Compliance	0.24	4.35	1.04	Very High
Site Stability	0.21	4.29	0.90	High
Training & Monitoring	0.16	4.12	0.66	Moderate
Cost Efficiency	0.12	3.98	0.48	Moderate

3.5 Relative Contribution of Major ESC Variables

The graph in **Figure 2** shows the percentage distribution of main erosion and sediment control (ESC) factors which affect construction operations throughout the USA. The research shows that Storm Water Management (SM) leads all other factors with a 26.0% contribution which demonstrates its essential function for managing water runoff and sediment movement and proper site water management. The 24.0% contribution from Regulatory Compliance (RC) demonstrates how environmental laws and permits and inspection requirements strongly affect ESC operations. Site Stability (SS) accounts for 21.0%, reflecting its importance in slope

protection and erosion prevention during construction activities. The Training & Monitoring (TM) program makes up 16.0% of the total because it helps workers learn about ESC and staff members continue to monitor the system for better performance. The research shows that Cost Efficiency (CE) makes up only 13.0% of the total impact which means economic factors play a smaller role than environmental and regulatory requirements when people decide about sustainable construction projects.

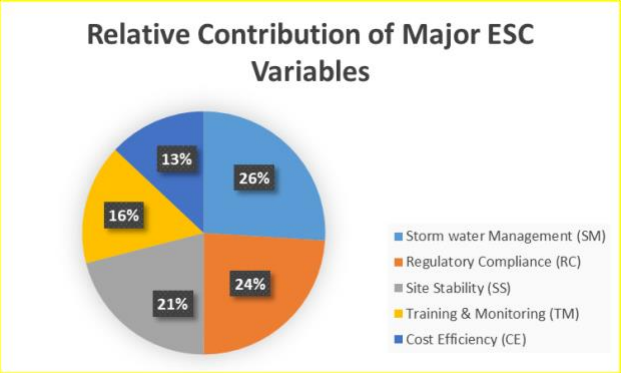

Figure 2. *Relative Contribution of Major ESC Variables*

4. Discussion

The research findings present a complete analysis of erosion and sediment control (ESC) methods which operate within the construction sector of the United States through a multi-criteria decision analysis (MCDA) system. The descriptive statistics show that storm water Management (SM) is the most influential factor, with the highest mean value (4.41). The system operates as a fundamental component which manages surface water flow to protect construction sites from erosion while ensuring proper drainage system functionality. Storm water functions as the primary vehicle which carries eroded soil so environmental protection activities need to focus on its management (Olsson et al., 2012). The Regulatory Compliance (RC) factor shows a high average score of 4.35 which demonstrates how environmental laws together with permitting systems and inspection requirements strongly affect ESC practices throughout the United States. The practice of ESC needs to fulfill technical standards and legal requirements at the same time. The Site Stability (SS) factor which has an average score of 4.29 shows that erosion prevention needs slope protection together with soil reinforcement and correct grading techniques. The Training and Monitoring (TM) factor which has an average score of 4.12 shows that employee training programs together with ongoing monitoring activities lead to better ESC results. The cost efficiency metric (CE) shows an average value of 3.98 which indicates that economic restrictions continue to exist although they do not represent the primary concern because environmental protection and sustainable practices now take precedence. The research instrument shows strong reliability through its Cronbach Alpha scores which fall between 0.79 and 0.88. The findings demonstrate that all testing elements maintain their internal consistency because the variables effectively measure ESC-related perceptions. The storm water Management system proves to be highly reliable because construction experts agree on its significance which strengthens the main analytical framework (Shahbazbeygi et al., 2021).

The correlation analysis shows that all ESC variables maintain strong positive connections which proves they work as one complete system instead of separate components (Cigna et al., 2020). The data shows storm water Management creates the strongest connection with Site Stability through a 0.73 correlation which proves that managing runoff water effectively stabilizes slopes while preventing soil erosion. The correlation analysis shows that storm water Management and Site Stability link strongly with Regulatory Compliance through 0.71 and 0.66 correlation values which demonstrate how regulatory systems support ESC implementation through technical methods. The data shows Training and Monitoring maintain steady connections with all variables while they show their strongest connection to storm water Management through a 0.69 correlation which proves human elements like knowledge and supervision and compliance behavior determine ESC performance success. Research indicates that Cost Efficiency displays moderate connection levels but its positive relationship shows organizations maintain economic values which they apply through indirect methods during their decision selection process (Pastukhov et al., 2021).

The MCDA results provide a clear prioritization structure for ESC factors. The evaluation assigns storm water Management and Regulatory Compliance as top-priority elements because they represent the main forces which determine ESC performance through their environmental protection and legal enforcement roles (Dagar et al., 2023). The site stability evaluation reached a 0.90 score which qualifies it for the highest level because it preserves soil stability throughout construction operations. The evaluation assigned Training and Monitoring a 0.66 score and Cost Efficiency a 0.48 score which places them in the "Moderate" category that shows their value to support ESC systems instead of serving as main decision factors. The analysis of percentage contributions supports these results because storm water Management (26%) and Regulatory Compliance (24%) form the two largest influence segments. The site stability element contributes 21% to the system while training and monitoring activities contribute 16% and cost efficiency measures provide 13%. The distribution shows that environmental and regulatory factors hold the most power to shape ESC decision-making frameworks (Liu et al., 2020).

5. Conclusion

The research established a multi-criteria decision analysis (MCDA) system which assesses erosion and sediment control (ESC) methods used by American construction companies. The research shows storm water Management and Regulatory Compliance serve as the primary elements which impact the situation. The research shows that ESC performance depends mostly on environmental and regulatory requirements instead of financial factors. The research proves that modern infrastructure development needs sustainable construction practices through integrated management systems and complete rule adherence and proper storm water control systems.

Author Contributions

A.M. conceived and designed the study, developed the methodology, conducted data analysis, and prepared the original draft. N.A. contributed to data collection, interpretation of results, manuscript review, editing, and supervision. Both authors read and approved the final manuscript.

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