APPLICATION OF THE ANALYTIC HIERARCHY PROCESS FOR MANAGEMENT OF SOIL EROSION IN OMAN

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ABSTRACT

The level of soil degradation worldwide is alarming due to its potential for causing serious problems such as threatening food security. The sultanate of Oman faces the problem of soil erosion which also disturbs waterways, infrastructure and agriculture. The problem of soil erosion has become increasingly apparent in Oman and is due to inappropriate land management. This occurs particularly with dams where sedimentation is a common issue and in the aflaj water systems. Currently, there are no appropriate methods being practiced that would overcome the problem of soil erosion in Oman, and no specific studies are available that discuss suitable methods for soil protection in Oman. Therefore, this study is an initiative to overcome the problem of soil erosion in Oman by proposing the best soil erosion protection method using the Analytic Hierarchy Process (AHP). In order to achieve this goal, this study reviews different methods of preventing soil erosion and the factors governing their selection. The important and controlling factors were considered in an AHP model to rank the soil erosion protection methods. Based on the AHP model, pairwise comparisons were conducted with the help of 15 experts from different sectors including authorities responsible for soil conservation in Oman, decision-making governmental departments and research institutes. The results of the AHP analysis indicated that the most suitable soil erosion protection method, based on the considered factors, is erosion control fences, followed by protection of the gully head and revetment. As no previous studies on suitable methods for soil conservation in Oman exist, this study bridges the gap by providing valuable information on the best soil protection methods that could help soil conservation authorities in Oman as they decide about possible future strategies.The study also indicated that the AHP model is a suitable guiding framework for decision-making because it involves a group of experts for the selection of soil protection methods based on the situation in Oman.

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1. Introduction

Soil is the earth's fragile skin that anchors all of life to Earth. It comprises countless species that create a dynamic and complex ecosystem and is one of the most precious resources to humans. The loss of half of the topsoil on the planet in the last 150 years can be attributed to the phenomenon of soil erosion (Pimentel, 2006). The loss of soil from land surfaces by erosion is a global issue, which has adverse effects on the productivity of all natural ecosystems including agriculture, forests and rangeland ecosystems. Soil erosion is considered a major environmental problem and is a cause of increased concern around the world (Avni, 2008; Pimentel, 2006). Over 35% of New South Wales in Australia is affected by some sort of soil erosion, which impacts the productivity of agricultural land and the quality of river systems and stormwater catchments due to sediment transport (Department of Environment and Climate Change NSW, 2007). It has been estimated that water erosion affects 41 million hectares of total area in the Near East and North Africa (NENA) region. Approximately 60% (135 million hectares) of soil degradation resulted from wind erosion, which makes it the most common environmental problem faced by the region. The cropped areas in the NENA region are severely affected by the accumulation of eroded material in agriculture fields, irrigation canals and water harvesting areas. The Gezira irrigation scheme in Sudan is an example of the problem. Here, wind erosion has resulted in sand encroaching which affects the efficiency of the irrigation system. Moreover, as a result of water and wind erosion, the area with fertile cultivated soil in the El-Witia area (Libya) decreased by 31% from 1986 to 1996, whereas the area with low fertile soils increased by 38% (Food and Agriculture Organization of the United Nations (FAO), 2015).

In arid and semi-arid regions, soil erosion has become a critical issue because it significantly affects the agricultural potential in those regions. The process of gully erosion within the drainage basins is very active in the rocky and hilly areas of the Middle East, such as most of Jordan, Syria and northern Egypt, and this severely decreases biodiversity, natural biomass, agricultural potential, and irrigation efficiency (Avni, 2008). Similar negative impacts of soil erosion have become increasingly apparent in Oman, especially in the case of dams and the aflaj water systems. The Omani government has built a number of recharge dams across wadis to detain runoff and recharge the aquifers, where groundwater reserves store approximately 99% of the demand for irrigation water (Prathapar & Bawain, 2014). The gully erosion within the drainage basins results in sediment transport along with water. These sediments settle upstream from the dam during detention and significantly reduce the rate of infiltration and recharge of the aquifers in Oman (Prathapar & Bawain, 2014). Moreover, 40% of the agricultural land in villages depends on the aflaj water system for irrigation. Sand encroachment into these aflaj water systems from soil erosion decreases irrigation efficiency and, therefore agricultural potential (Prathapar & Bawain, 2014). The only possible way to deal with these issues is to adopt a suitable method for the prevention of soil erosion, but currently no information is available on proper practices of soil protection in Oman due to the lack of specific studies based on the situation.

The decision to select an appropriate soil protection method is complex and involves many factors, such as types and characteristics of soil, climate and cost of the soil protection methods. As the number and complexity of soil protection methods for conservation of soil grows, so do the strategic judgements required for the effective assessment of these soil erosion protection methods. This has led to the popularity of multi-criteria decision analysis (MCDA) methods being used in environmental decision-making (Loken, 2007). This research opted to use a MCDA technique, specifically the Analytic Hierarchy Process (AHP), to address Oman's growing soil erosion problem by selecting the best soil protection method while considering the factors influencing their performance. This research will hopefully bridge the gap between insufficient knowledge on suitable methods for preventing soil erosion that can be adopted in Oman and the controlling criteria, and will assist the Omani authorities who are responsible for soil protection in decision-making.

2. Methodology

The AHP method, which was developed by Thomas Saaty in 1970, allows decision makers to arrange the complex problem into a multilevel hierarchy structure (Saaty, 1980). The top level of the hierarchy structure represents the goal of the study, the middle level represents the criteria and the lowest level consists of the alternatives (Alexander, 2012). It allows decision makers to conduct pairwise comparisons to evaluate the importance of the variables in each level of the hierarchy, and the alternatives present in the lowest level to make the best decision from among the several alternatives. Moreover, this method performs a consistency test to screen out inconsistent judgements. The effectiveness of the AHP method has led to its popularity in research. Furthermore, the international scientific community that deals with complex decision problems has declared the AHP method a robust and flexible method (Ehrgott, 2010). The forthcoming steps of the AHP method that were developed by Saaty have been followed in this study (Nixon, Dey, Ghosh, & Davis, 2013; Saaty, 1980; Saaty & Sagir, 2009; Qazi, Abushammala & Azam, 2018).

2.1 Define Objective

This stage includes defining the objective statement, which is to rank the soil erosion protection methods for soil conservation in Oman and the factors influencing the goal.

2.2 Construct hierarchy structure

The next phase is the construction of the problem as a hierarchy. This involves splitting the goals, criteria and alternatives of the complex problem into multiple levels.

2.3 Make a pairwise comparison to generate a matrix

Once the hierarchy structure is developed, a pairwise comparison is performed to form judgmental matrices. First, the pairwise comparison of the selected criteria is performed with respect to the objective of study, and then the comparison between the alternatives with respect to the individual criterion is performed. Saaty's nine-level standardized comparison scale which is illustrated in Table 1 was used to assign the judgements in the pairwise comparisons (Ehrgott, 2010).

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Table 1
Saaty's nine-point scale for pairwise comparison

Numerical Rating	Verbal Judgments of Preferences between Alternatives *i* and Alternatives *j*
1	*i* is equally important to *j*
3	*i* is slightly more important than *j*
5	*i* is strongly more important than *j*
7	*i* is very strongly more important than *j*
9	*i* is extremely more important than *j*
2,4,6,8	Intermediate values

2.4 Determine the priorities of the alternatives

In order to determine the priorities of alternatives, the AHP methodology was used with the assistance of the Super Decisions software to solve the judgmental matrices. The results obtained from the pairwise comparisons were inserted into the Super Decisions software, which uses the principles of the AHP methodology. The working principle of the AHP method involves the computation of local priority vectors (PVE) by normalizing the vectors in each column of the matrix, followed by the calculation of the average of the resulting matrix. The global priorities of each alternative are then computed by synthesizing the local priorities over the hierarchy.

3. Results and discussion

3.1 AHP model development

The main objective of this research was to select the best soil erosion protection method to conserve soil in Oman and control the problem of sediment which affects water quality. In order to apply the AHP method, a consultation with a group of experts was carried out to identify/modify the soil erosion protection methods and the criteria influencing their selection. After a thorough literature review, a consultation process was conducted with 15 experts from different sectors including authorities responsible for soil conservation in Oman, decision-making governmental departments and research institutes. The expert advisory group was formed based on their related knowledge background and experience in the field of study and involved specialists from different organizations. The group comprises managers whose duties include performance monitoring and measurement, and experts from several operational levels such as engineers and technicians, academic staff, and consultants. Finally, based on the AHP method, the modified criteria and alternatives were distributed into a multi-level hierarchy structure as illustrated in Figure 1.

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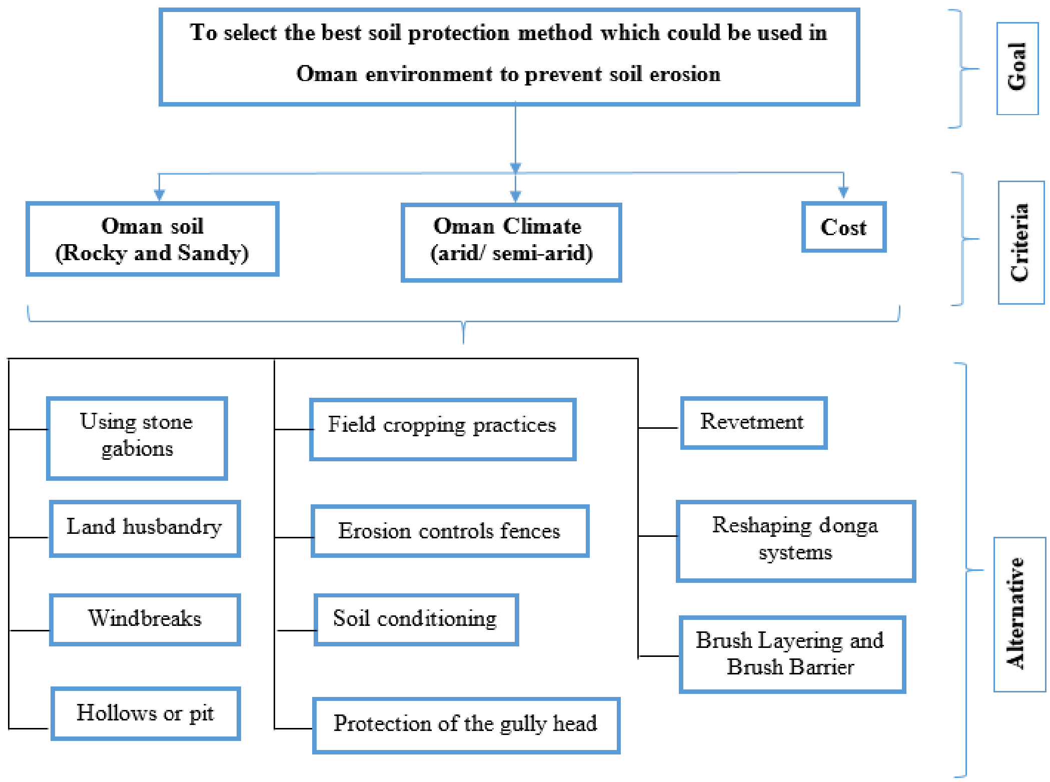

Figure 1 Hierarchy structure

The hierarchy is arranged into three levels (Figure 1). The top level consists of the goals of the current study. The middle level is comprised of the main criteria including the types and characteristics of soil in Oman (rocky and sandy), the climate of Oman (arid/semi-arid climate) and the cost of the soil protection methods, which are discussed in Table 2. Meanwhile, the bottom level represents the alternatives which includes stone gabions, land husbandry, windbreaks, hollows or pits, soil conditioning, field cropping practices, erosion control fences, protection of the gully head, reshaping gully systems, revetments, and brush mattress as shown in Table 3.

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Table 2
Finalized criteria with description

Criteria	Description
Type and Characteristics of Soil	Considering the type and characteristics of the soil is important for selecting the appropriate soil protection method, as soil erodibility is an estimate of the soil's ability to resist erosion, depending on the physical characteristics of each type of soil. The texture of soil is a factor that affects erodibility, however permeability, organic matter and structure are also important. For instance, soils with high infiltration rates, organic matter and better soil structure show better resistance to erosion; whereas, sandy loam, sand and loam textured soils are less susceptible to erosion than very fine sand, silt and certain clay textured soils. This factor helps determine how vulnerable the soil is to erosion, and the level and type of soil protection measures that should be taken (El-Swaify, 1997; Ritter, 2012).
Climate	Soil erosion is the process of the topsoil being worn away by natural physical forces like wind and water, or through tillage. Therefore, climate has a great influence on the selection of a soil erosion prevention method because it helps identify the sort of erosion that prevails in the particular region, i.e., wind erosion or water erosion. Depending on the reason for the land degradation, a better and effective soil erosion prevention method can be adopted that targets the specific type of erosion (El-Swaify, 1997; Ritter, 2012).
Cost of Soil Protection Method	The cost of soil protection methods varies and hence, this factor should be considered in order to make an economically sound decision. Not only should the adopted method help reduce the soil erosion, but it should also be economically feasible. Therefore, the cost involved in implementing the strategy and its operational and maintenance cost should be taken into account (El-Swaify, 1997).

Table 3
Alternatives selection and description

Alternatives	Description
Stone Gabion	Gabions are baskets composed of hexagonal woven wire mesh. When filled with rocks, these baskets form flexible and permeable structures like a retaining wall to control erosion. The wires are either heavily zinc coated, PVC coated or are made of stainless steel. Stone gabions are available in various sizes, but the most popular size is 2 m long x 1 m wide x 1 m tall (South African National Roads Agency, n.d.).
Land Husbandry	This method involves the active management of vegetation, rainwater, soils and slopes so that there is an increase or no loss of stability, productivity and usefulness for the chosen purpose. This management is performed in a wide range of environments from fields to landscapes, with native vegetation of every kind, and in pastures and plantations (Overseas Development Institute, 1997).
Windbreaks	Windbreaks are trees planted in rows to prevent wind from causing soil erosion. The number of rows in a windbreak depends on the space available and the reason for planting them. However, the windbreaks that are intended to reduce soil erosion usually consist of a single row that is planted parallel to the cropping patterns (Wilson & Josiah, 2004).
Hollow or Pit	Pits are planted to harvest precipitation which in turn prevents water runoff, reduces erosion and increases infiltration. Pits are holes that are 5-15 cm deep that are dug 50-100 cm apart from each other. This method not only reduces soil erosion, but also helps stabilize production of crops by increasing soil moisture or allowing irrigation in a dry period (Bot & Benites, 2005; Waelti & Spuhler, 2019).
Soil Conditioning	The use of soil conditioners or composted mulch is another way to reduce the direct impact of wind and rain on the soil surface, improve soil structure, water holding capacity, and water infiltration, increase plant growth and reduce runoff. It causes an increase in plant growth which is crucial for long-term erosion control (Department of Environment and Climate Change NSW, 2007).
Field Cropping Practice	In this method, a series of different types of crops are grown on the given land area in sequential seasons. Growing only one type of crop for a long time weakens the soil and leaves it uncovered for periods of time, making it susceptible to erosion. This method promotes soil health by restoring nutrients and mitigating the accumulation of pathogens and pests which results from growing

	only one plant species (Hillel & Hatfield, 2005).
Erosion Control Fences	These fences are made up of synthetic geotextile fabric that is woven to provide small openings to let water pass through and retain sediments. The low permeability rates of these fences allow sediments to settle and water to pass through slowly. They have been used in the construction industry for decades to keep soil on construction sites. Erosion control fences work best when they are installed on uniform slopes with few obstructions (Robichaud & Brown, 2002; U.S. Environmental Protection Agency, 2012).
Protection of the Gully Head	In this method, diversions are constructed above the gully area to divert runoff away from the gully heads to reduce scouring, and to let sediments accumulate and allow vegetation to grow in the gullies. Since surface water runoff erodes soil along drainage lines, it is important to protect gully heads and prevent headward erosion (Department of Economic Development, 2017; Geyik, 1986).
Revetments	Revetments are onshore structures which protect the shoreline from erosion, infiltration by water or scouring by waves to ensure and improve the stability of bank slopes. These structures are usually made of a layer of concrete, stone, asphalt or masonry to shield the natural sloping shorelines (New York State Department of Environmental Conservation, n.d.; OYO International Corporation, 2007).
Brush Mattress	This method involves laying a brush mattress on a slope and fastening it with wire and stakes. These mattresses provide dense woody vegetation on slopes allowing them to protect the soil surface from erosive forces. They are used mainly on streambanks where the velocity is less than 6 feet per second and erosive conditions are formed due to excessive runoff (New York State Department of Environmental Conservation, 2005).
Reshaping Gulley Systems	This method should be adopted in cases where the gulley systems are very severely eroded with crumbling, collapsing and dried out vertical sidewalls. In such cases, it is more practical to reshape the gulley system entirely. When gulley heads and banks are reshaped, they should be shaped into a gentle slope (1:1 slope) (Conservation Management Services, 2015; Geyik, 1986).

3.2 Application of the AHP

A total of four matrices were arranged for pairwise comparison based on the AHP methodology. The first matrix presented a pairwise comparison of the criteria with respect to the goal of the study, and the other three matrices involved in the pairwise comparison of soil protection methods with respect to each criterion (Oman soil, Oman climate and cost). The matrices were formed by the judgements of 15 experts, who

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allocated a numerical rating for the comparison of each element in the questionnaire from Saaty's nine-point scale (Table 1). Only two questionnaires failed the consistency test and were removed from the study, while the remaining 13 questionnaires proved to be valid and usable because most of the judgements that were given by the experts were consistent. Next, the hierarchy structure and judgements that were obtained from all of the valid questionnaires were inserted in the Super Decisions software, which processes data based on the AHP methodology. The results of the ranking of the soil protection methods computed by the software are displayed in terms of ideal priorities, normalized priorities and raw priorities (Figure 2).

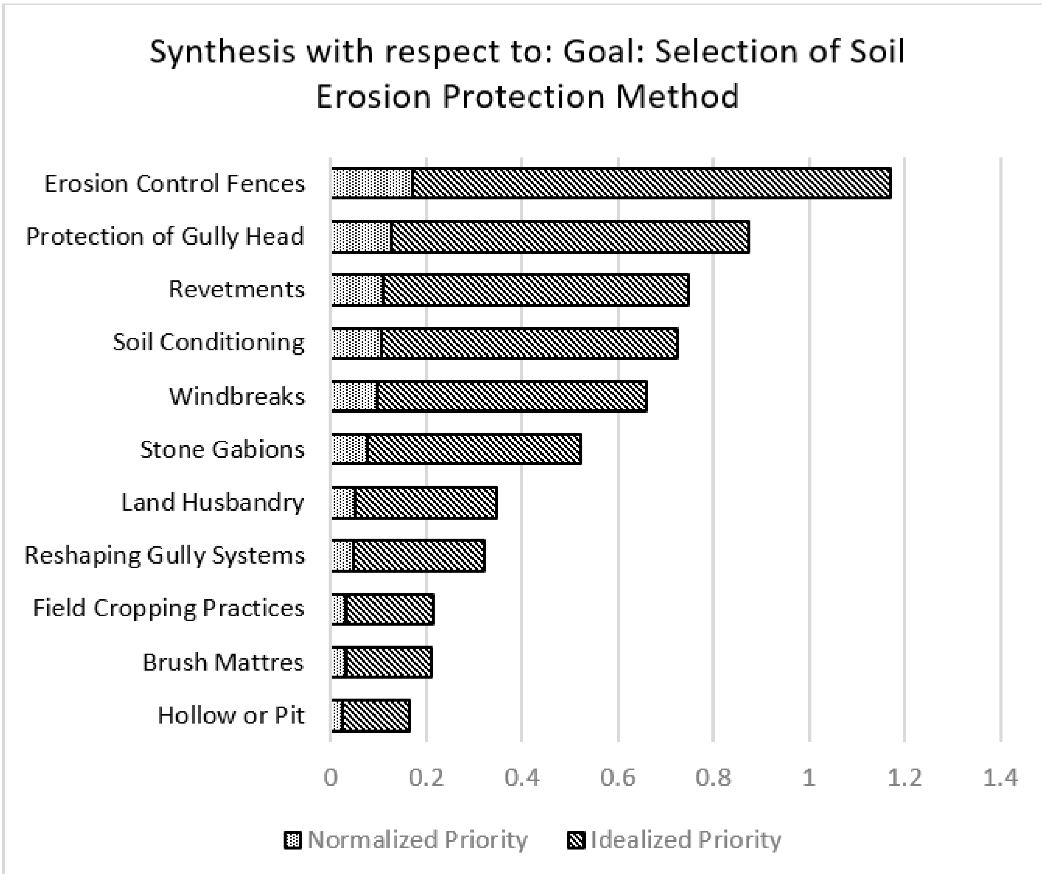

Figure 2 Overall priorities of all of the alternatives obtained from the Super Decisions software

The idealized priorities were obtained by dividing the limiting column by the largest values in the column. Consequently, the results showed that the 'protection of the gully head' method has 74.7% of the appeal of the 'erosion control fences' method, 'revetment' has about 63.7%, 'soil conditioning' has 62%, 'wind breaks' has 56.2%, and 'using stone gabions' is about 44.8% as appealing as the 'erosion control fences' method.

The analysis in this study showed that the best soil erosion protection method based on the conditions in Oman is the ‘erosion control fences’ method, followed by ‘protection of the gully head’, ‘revetment’, ‘soil conditioning’, ‘wind breaks’ and ‘using stone gabions’.

4. Conclusion

This study assessed the different soil erosion protection methods for soil conservation in Oman using the AHP technique. Tackling soil erosion is a pressing need because of the problems that erosion causes. The study demonstrates that the AHP model is a suitable guiding framework for decision-making because it involves a group of experts for the selection of soil protection methods based on the situation in Oman. Based on the criteria preference for soil conservation in Oman, the results from the AHP analysis show that the ‘erosion control fences’ method is the best performing option followed by ‘protection of the gully head’ and ‘revetment’.

The erosion control fences method to prevent soil erosion has huge future potential in Oman because the country has mostly rocky and hilly areas which are prone to soil erosion during heavy rains. This method is very beneficial and suitable for Oman because it works best when installed on uniform slopes. When used in this manner, these fences could help keep the eroded soil on the slopes and prevent its intrusion onto the highways and roads, and therefore keep it out of wadis and waterways. Moreover, the process of gully erosion within the wadis is also very active in Oman, and by adopting either the gully head protection method or revetments, as proposed by this study, the shorelines could be protected from erosion and scouring. The gully head protection method would promote sediment accumulation and vegetation growth in wadis as well. Overall, the proposed methods to conserve soil in Oman have huge future potential. Additionally, the adoption of these strategies to address the problem at the point of origin would help protect the waterways from sediment, the quality of the water, and the agricultural area, and would also help maintain the efficiency of the irrigation systems in Oman.

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