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ABSTRACT

The Wadi Rum Protected Area (WRPA) was formed to protect and conserve a typical area of the Eastern Desert land type. It is one of the United Nations Educational, Scientific and Cultural Organization's UNESCO world heritage sites. Erosion and tourism have had a negative impact on this region's natural and environmental life. Using satellite images acquired in the period from 1987 to 2018, this research intended to discover any influence of erosion on the geological structure of (WRPA) and any potential of floods, using the topographic wetland-index analysis. Supervised classification was used to construct land-cover/land-use maps of WRPA. The findings revealed a shift in Wadi deposits, but no change in mountain ranges, indicating that satellite photos might anticipate soil erosion. The topographic wetland-index analysis showed that the area could be classified as a medium-to-high-potential flooding area with values from 14.3 to 29. Furthermore, it is suggested that high-resolution satellite images be used to investigate the impact of human activities in the region on the ecosystem and vegetation. Because the utilized satellite images did not reflect the height of the mountains, further research using various remote-sensing methods should be conducted for such monitoring.

KEYWORDS: Heritage conservation, Protected area, Remote sensing, Erosion impact, Topographic wetness index.

INTRODUCTION

Wadi Rum Protected Area (WRPA) is often regarded as Jordan's most breathtaking natural attraction. This is because of its expansive desert, enormous mountain cliffs and boundless sky. There are plants in Wadi Rum that are not just uncommon, but also unique to the ecology there. A baseline study revealed the presence of the Ibex, the Sand Cat, the Brand Ford's Fox and the Gray Wolf in the region. The location has been identified as home to 120 different kinds of birds, including eagles, vultures, buzzards and sparrows, making it an excellent location for bird watching. There is a variety of outdoor activities available at Wadi Rum, including camel and horse safaris, rock climbing and hiking. Some of the caves in Wadi Rum are as old as the Nabataeans and were carved by hand. Visitor-friendly natural attractions include camping beneath the stars in a desert setting that is believed to be an experience that visitors will never forget. During their time there, they eat local traditional cuisine, are entertained by Bedouin songs and dances and spend the night in tents similar to those used by the Bedouin people (El-Harami, 2014).

Global legislation and practice have increased the use of protected areas as a conservation and preservation tool. New and growing risks to biodiversity have refocused attention on protected areas and their importance in improving adaptation. It is nonetheless necessary to link and integrate environmental management systems and expertise with the legislation that controls protected areas, as well as with the

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governance entity within which such areas are formed and maintained, where remarkable progress and improvements that have led to a basic framework of guidelines for their formation and administration (General Corporation for Environmental Protection, 2001).

The first rules and legislations on protected areas' law were released by the International Union for Conservation of Nature (IUCN)-Environmental Law Centre in 1980. Even after then, ecosystems have faced increasing risks from a variety of agents, such as habitat loss, extractive activity, climate change and a variety of other causes. Biodiversity problems from tourism are on the rise, particularly in places with poor governance and law enforcement. Environmentally sensitive regions outside protected areas and tourist hotspots are included in this category as locations where tourism demand rises due to growing worldwide prominence (SEA, 2022).

According to Jordanian law, a protected area is a land or sea area devoted to the conservation of biodiversity, natural resources, the environment and cultural heritage. The following factors must be considered while choosing a special protected area in Jordan (National Parks and Gardens Law, 2012): It ought to be outside of the national network of natural reserves, the region should have a cultural legacy tied to environmental value and should be modified and fit with the national-development economic goals.

Soil erosion is defined by three processes: soil loosening, transport and sedimentation. These acts generally result in the transportation of the top soil, which is rich in nutrients, organics and soil life, to another area on-site, where it may expand over time, or off-site, where it can gather in drainage routes and channels. Shi et al. (2012) found that it is more widespread in sloppy protected areas. Soil erosion has a negative impact on plant evolution, agricultural harvests, water quality and the recovery of protected areas. It is a major cause of soil decline and degradation which occur in all locations (Posthumus et al., 2015). Wind and water are the primary causes of soil erosion, both contributing to a significant amount of annual soil damage (Ding et al., 2015). Soil erosion, especially in protected areas, is one of the most serious global environmental issues. This is because it causes not just nutrient depletion in the soil and land declination, but also the loss of various important geological features in protected regions. The erosion issue is becoming a major stumbling block to the long-term development of natural and geological fortunes in protected areas, necessitating adequate monitoring, estimation and evaluation utilizing automated approaches (Issaka & Ashraf, 2017). Soil erosion causes permanent on-site soil damage, spoilage and deterioration and is quantified by calculating the average amount of separated soil from a given region during a certain time period. The sediment yield is the amount of soil separated and transferred to surface-water bodies over a time scale across a certain region and it is an essential approach in preventing watershed erosion in protected areas (Guo et al., 2015). As a result of 20 years of research, the impact of increased tourism on the deterioration of the rock at WRPA is obvious. It is becoming more difficult to preserve the unique features and nature of Petra and Wadi Rum with uncontrolled tourism in Southern Jordan. Damage and fragmentation of rocks may be accelerated by increased tourism activities *via* physical contact, such as climbing. The preservation and conservation of these exceptional environments need practical research to help understand weathering effects, because sandstone degradation in southern Jordan is a complicated and sensitive problem that we are slowly starting to grasp through research (Paradise, 2002). Anyhow, studying the effect of human touristic activities on soil erosion and surface texture of rocks in WRPA needs further investigation.

Satellite remote sensing may provide a substantial contribution to erosion calculations at many geographic scales due to the variety of space-borne sensors now orbiting the planet. Satellite data, particularly in data-poor locations, may aid in the quick mapping of erosion across wide areas, which would otherwise need costly and time-consuming surveying processes. The general public may access a variety of satellites (Luleva, 2013). Although certain image kinds are still expensive, much data is affordable or free, making it more accessible to a wider audience. As a result, satellite imagery is becoming more widely used for erosion research. This may be accomplished by exposing erosion lineaments and eroded areas or by calculating erosion parameters, like slope and plant cover (Vrieling, 2007). In erosion studies, remote sensing has been used to obtain input data for erosion models, to estimate soil erosion indirectly through plant-cover analysis and to display erosion markings and soil degradation processes directly (Shoshany et al., 2013). Direct procedures allow for the identification and delineation of specific erosion signs and characteristics, such as sediment depositions, water streams, valleys and gullies or eroded areas (Alatorre & Beguera, 2009; Arapatka & Netopil, 2010).

The potential and accuracy of using spectral imaging to identify degraded soils depend on the severity of erosion activities and the spectral features of disturbed soils. The visual performance of aerial images using soil color and its fluctuations is commonly utilized in remote sensing to identify degraded areas (Fulajtár et al., 2016). Several researchers, including Sarda (2019), used remotely sensed data and GIS tools to analyze terrain instability in India. The findings of the study were used to develop a hazard map for the area, which divided it into low-, medium-, high- and very high-risk zones depending on the potential of landslide occurrence. As digital remote sensing and satellite data continue to improve, the ability to analyze larger areas and quantify classification accuracy is becoming more feasible (Arapatka & Netopil, 2010).

Although pixel-based classification algorithms are simple to implement (Li et al., 2014), when there is a lot of spectral variation within a class and numerous areas are having a mixed effect, their efficacy may be called into question, especially if the surface soil is quite heterogeneous. Other research studies have suggested an integration of automatic classification and visual interpretation using remote-sensing procedures (Báová & Krása, 2016; Arapatka & Netopil, 2010). In order to accurately classify soil erosion, Fulajtár et al. (2016) recommended that further data be collected with using such classification algorithms. Sub-pixel analysis, fuzzy classification or spatial-context satellite image classification may be used to overcome the issues associated with pixel-based approaches (Li et al., 2014; Rabah & Farah, 2016; Wang et al., 2015; Schmid et al., 2016; Mayr et al., 2016). At the same time, improved resolution data in the spectral domain of satellite images must be used to increase the accuracy of erosion-degraded soil classification (Ala et al., 2017; Chabrillat et al., 2014; Schmid et al., 2016). As a result, multi-spectral Landsat satellite images and high-resolution data from satellites are widely used and utilized in soil-erosion studies. (Luleva et al., 2013; Sepuru & Dube, 2017).

In the development of risk-preventive actions, estimating floods is crucial. A statistical methodology called flood-frequency analysis may be used to predict the potential of floods of varying magnitudes happening at a given location in the future and these conventional techniques are based on this concept. Because of the infrequency of floods, rainfall-based methods must be utilized in the absence of adequate flood data. Historical rainfall data is combined with computer simulations depending on the area's physical attributes (such as watershed and stream length) and these simulations are impacted by changes in precipitation and climate change. When it comes to large-scale flood monitoring, using remote-sensing precipitation data, the Flood Potential Index is commonly employed. Due to this, indirect measures, like the Topographic Wetness Index (TWI), are regarded reliable for monitoring floods in cloudy weather (Sun et al., 2017). TWI can quantify the influence of topography on run-off caused by rainfall, since the TWI value may indicate the amount of wetness of the ground, which is considered to be connected with flood vulnerability (Mahfudz et al., 2022).

Wadi Rum protected area in Jordan is the focus of this investigation, which attempts to determine the significance of using remote-sensing techniques in order to determine the effect of erosion and flooding on the area. In addition to this, the study is exploring whether or not tourism has had any adverse effects on the natural and environmental life of this area, by evaluating the change in the landcover over time using time-series satellite images.

Study Area

WRPA is a combined World Heritage site situated in southern Jordan near the Saudi Arabian border, about 290 kilometers south of Amman and 60 kilometers northeast of the seaside city of Aqaba, as depicted in Figure 1. WRPA is a mixed natural and cultural site with a wide variety of desert features, including a number of valleys, arches, ramps, enormous landslides and caves. In this area, it is possible to follow the development of the alphabet and human intellect *via* the study of 25,000 rock carvings and 20,000 written inscriptions. The area's pastoral, agricultural and urban development may be seen at this location (UNESCO, 2011).

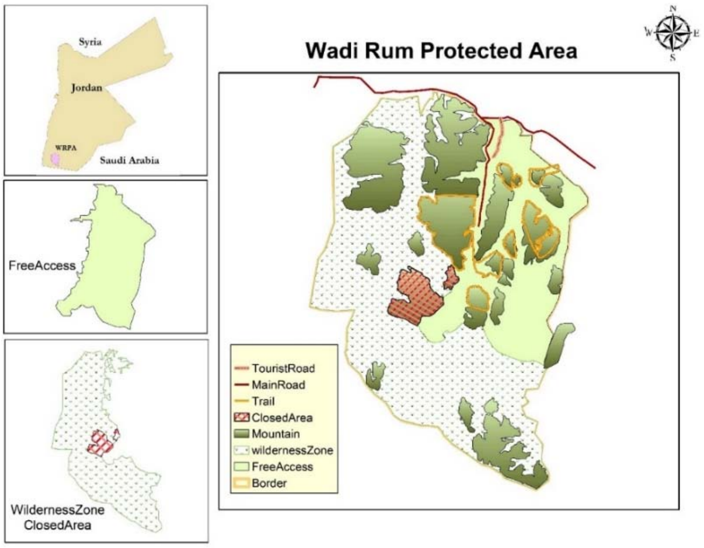

Figure (1): Location map of Wadi Rum protected area (IUCN, 2011)

Table 1. Landsat images used in the study

Date of acquisition	Spatial resolution	Number of bands	Path	Row	Landsat sensor
Apr 08, 1987	30m	4	Landsat 5 TM	39	174
Aug 03, 1992	30m	4	Landsat 5 TM	39	174
Oct 04, 2000	30m	7	Landsat 5 TM	39	174
Dec 03, 2010	30m	7	Landsat 5 TM	39	174
Oct 14, 2018	30m	11	Landsat 8 OLI	39	174

WRPA has a total area of 74,200 hectares. The property is 42 kilometers long from north to south and 33 kilometers long from east to west. A 5-km buffer zone surrounds the nominated region, with certain exceptions and is reported to have a total size of 60,000 hectares. Temperatures in summer may range from 16 degrees Celsius to 45 degrees Celsius and the relative humidity is often about 26 percent. In winter, highs and lows typically range from -1.5 degrees Celsius to 31 degrees Celsius. In winter, precipitation may range anywhere from 50 to 100 millimeters on average, although severe droughts have become increasingly regular in recent years (IUCN, 2011). The number of visitors visiting the wildlife reserve next to Wadi Rum has been gradually increasing since the middle of the 1970s, particularly after the peace treaty that was signed in 1994. During the high tourist season, the town of Rum and its outlying neighborhoods get an average of 250 tourists every day. In the highlands of the proposed reserve, guests will be able to climb with Bedouin guides and go on off-road desert safaris that stretch for several days. There are additional adventures that include rock climbing (Evans et al., 2005).

It is self-evident that the WRPA is mostly made up of the following kinds of soil and rock: mountains' sandstone and sandstone deposits of various hues, ranging from rust red to yellow to virtually pure white, are generated by varying amounts of oxidation and secondary iron mineral composition within the mainly quartz sandstone (SEA, 2022). The drainage system from a previous, wetter epoch may be seen at the northern limit in the form of a string of long, dry mudflats. Since the Paleolithic period, living species have depended on the two large and eleven smaller springs that may be found where sandstone meets shield rock. These springs can be found in the same general area. The one at the eastern base of Jabal Rum was the one that designated where the village and fortifications of Rum were located (NBSAP, 2020).

Local communities are authorized to harvest woody fuels for subsistence purposes, although these activities are considered to be within reasonable limitations at this time. The region does not have any economically viable mineral resources, thus mining is not a concern (ICOMOS -IUCN, 2014).

Data Collection and Work Methodology

Landsat satellite images from the years between 1987 and 2018 with the help of supervised classification were used to construct landcover/land-use maps of the research area. Five satellite images were collected from the US Geological Services (USGS) and studied to demonstrate the temporal variations of erosion and their influence on the geological structure of WRPA. The satellite images utilized in this investigation are shown in Table 1. In order to give an idea about the nature of the study area, Figure 2 shows a sample of the used satellite images in the beginning and the end of the study period.

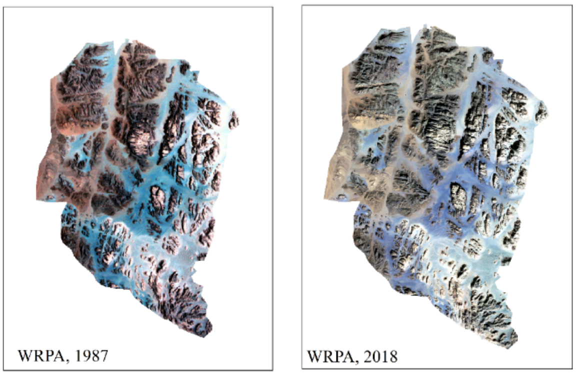

Figure (2): The used satellite images of WRPA

Land-cover classification was done using medium-resolution satellite pictures to detect and assess the impact of erosion on the study region over time, while pixel-based classification was utilized for that purpose using PCI Geomatica software. Because it is critical to track each class and observe its transition, all land-cover classes that exist in the research area were tracked in this study. To map land classes from Landsat images, an image-classification technique paired with a GIS process using ArcMap software has been used. Then, using post-classification change detection, the spatial changes throughout the whole region were examined. Figure 3 depicts the used technique of change detection in this research.

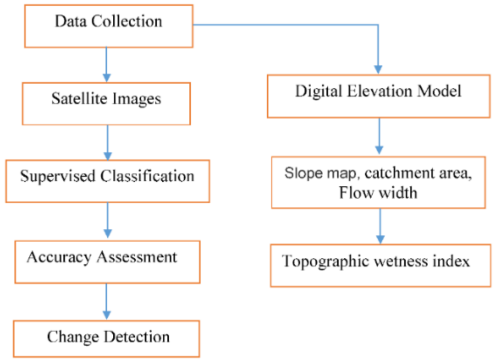

Figure (3): Data collection and work methodology flowchart

Based on Kopecky et al. (2021), digital elevation model is the reference to develop TWI. The catchment size, flow breadth and slope are all calculated once the DEM has been cleared of any sinks. Equation (1) is usually used to determine the TWI:

$$TWI = \ln\left[\frac{\left(\frac{TCA}{FW}\right)}{\tan S}\right] \quad (1)$$

There are three variables in this equation: total catchment area (TCA), flow width (FW) and slope (S).

RESULTS AND DISCUSSION

The image-classification findings indicated that the utilized maximum likelihood classifier had a high accuracy, with an average accuracy ranging from 88% to 92%, as well as a high overall accuracy of roughly 91 percent and a Kappa value of 0.94. The categorization results of the utilized satellite images are shown in Figure 4.

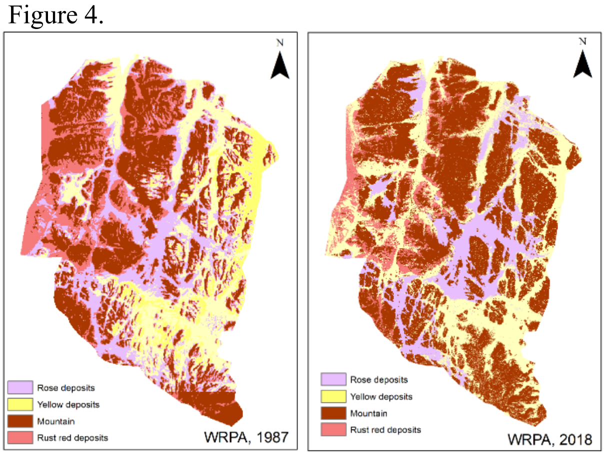

Figure (4): Classification results of the used satellite images in 1987 and 2018

Figure 5(a) shows the extracted land-cover class percentages of the Landsat satellite image in the year 1987, while Figure 5(b) shows the extracted land-cover class percentages of the Landsat satellite image in the year 2018.

The threat in WRPA can be divided into low threat and high threat. With 300,000 visitors a year as of 2010, the impact of these tours is a high threat inside the protected area. Grazing is considered as a low threat to the area, because local communities transfer from livestock farming to tourism-based economy. There is also the potential for climate-change impacts on flora and fauna dependent on the elevated mountainous areas of Wadi Rum. With growing visitor numbers and associated pressures, the finalization of the new draft management plan and ensuring sufficient capacity to implement it represent a priority (ICOMOS -IUCN, 2014). According to unofficial statistics, the number of off-road vehicles in the vicinity has been steadily growing since 2011 and may have exceeded 1,000-1,500 by 2019. Excessive 4WD-vehicle use in the region caused a significant damage to flora and fauna, as well as noticeable aesthetic scars, in 2011 (UNEP-WCMC, 2017).

Table 2. Percentage of land-cover classes during the study period

Landcover	1987	1992	2000	2010	2018
Desert Plants	0	0	0.99	0.08	0.06
Villages	0	0	0.01	0.91	0.52
Mountain	25.42	24.71	23.19	21.92	23.46
Top Mount Sand	0.87	4.55	2.70	4.02	4.81
Rose Soil	11.73	10.31	11.15	7.71	6.76
Soft Soil	7.11	7.98	9.17	8.24	8.12
Shale	7.49	6.69	5.53	5.02	6.28
Rocky Soil	4.19	2.48	3.96	6.18	6.72
Soil	1.57	1.83	1.40	3.48	2.46
Shadow	1.65	1.55	1.99	2.54	1.01

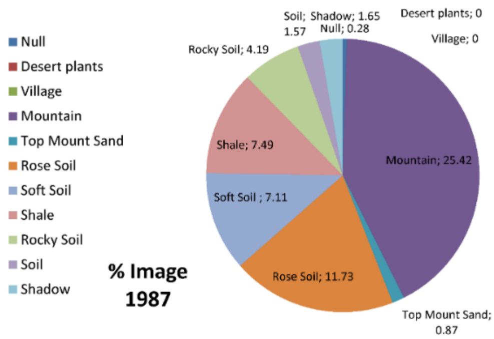

Figure 5 (a): Classification results showing the percentage of each land-cover class in the year 1987

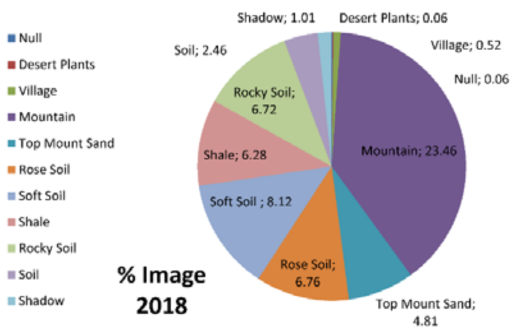

Figure 5 (b): Classification results showing the percentage of each land-cover class in the year 2018

It is impossible to observe the direct significant impact of erosion during such a short period of time, yet it normally takes thousands of years. The alteration of deposits in the corridors and canyons is the most visible change in this region. Wadis are also covered with varied shades of loose sand and dunes. These deposits were most likely transported by water and wind from other locations to the WRPA, although they might possibly have come from the tops of the mountains in minor quantities, as well as from safari vehicles which are essential for breaking down tiny rocks and transitioning between deposits. This goes with Paradise (2002) who stated that the area is unique for the unusual combination of landforms that have been produced there as a result of the carving of streams, the extensive weathering caused by salt, biological and other processes and the erosion of steep sandstone cliffs.

Figure 6 shows the theoretical geologic cross-section of Rum Mountain, Um Ishrin Mountain, Barrah Mountain and Maharraq Mountain, each of which has different colors depending on its mineral composition.

In WRPA, the change is generally proportionate to the rising impact of erosion and sediment transport, as shown in Table 2. This sediment transport affects the current plant cover and animals, fluctuating from season to season during each year. Tourism puts strain on the WRPA, since Jeep safaris are of special concern and seem to be having the greatest influence on property values, while the general number of vehicles exceeds safe limits, as stated by the WRPA (IUCN, 2011).

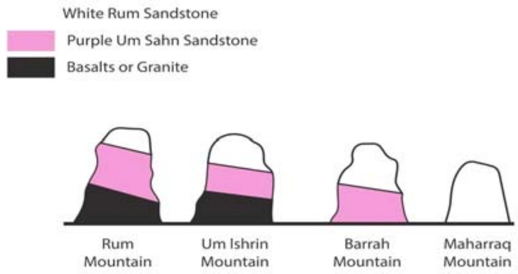

Figure (6): A diagram of the theoretical geologic cross-section of Rum mountain, Um Ishrin mountain, Barrah mountain and Maharraq mountain (Bender, 1974)

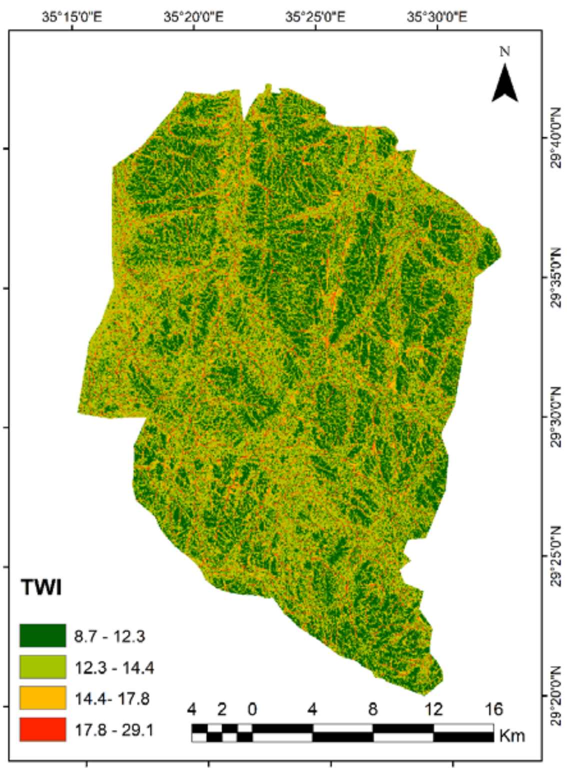

Figure (7): TWI map of the WRPA

The results of TWI are displayed in Table 3. The topographic wetland-index analysis showed that the WRPA could be classified as of medium-to-high potential flooding with values from 14.3 to 29. This reflects the risk of possible floods in the area, as it provides an idea about the potential surface-water accumulation zones (Gruber and Peckham, 2009). Probability-density technique has been utilized as suggested by Prawiradisastra (2018) to categorize the potential flooding levels. Figure 7 depicts the generated TWI map of WRPA, which is used to detect the potential locations of floods.

Table 3. Potential flooding levels (Prawiradisastra, 2018)

TWI	Potential flooding level
1. 0.00 – 13.57	No Potential
2. 13.57 – 15.63	Low Potential
3. 15.63 – 17.27	Medium Potential
4. 17.27 – 34.40	High Potential

Between the major visiting attractions, a single-track network has been constructed, although it is almost difficult to enforce. The WRPA's executives are well aware of the gravity of the problem and are dedicated to addressing it in the new management strategy. Expert assistance on mitigating the consequences of erosion is also being sought. Reducing the number of jeeps on the road must be accompanied with the promotion of more environment-friendly tourist activities, like camel trekking, walking and rock climbing.

CONCLUSIONS AND RECOMMENDATIONS

The major conclusions of this study are:

1. Remote-sensing methods were utilized in this research to investigate the impact of erosion on the heritage and protected area in the WRPA. Using Landsat satellite images from 1987 to 2018, it is obvious that remote-sensing techniques are effective for studying erosion impacts, with an average accuracy ranging from 88 to 92 percent, a high overall accuracy of around 91 percent and a Kappa value of 0.94.
2. Erosion has a substantial impact on WRPA and the primary change in the research region is the rising and changing quantity of deposits. A rise in the impact of erosion is unquestionably a significant development, particularly in a hiking region.

3. Since satellite images monitor the region from the top, it is impossible to observe the erosion impact on the cliffs or side sections of the mountain. New images that indicate the height of the mountain are highly recommended for this kind of monitoring.

The following recommendations could be proposed:

1. It is suggested that the region be monitored using a Lidar system in order to identify the key erosion-affected mountains for future planning and consideration. When it comes to the likelihood of flooding, the region is categorized as moderate-to-high in severity with values from 14.3 to 29.
2. It is strongly advised that the government adopts appropriate measures to cope with major floods in the future, including the installation of an early warning system in the area, as well as the construction of specific flood-mitigation and -routing structures.
3. Further research employing higher spatial resolution satellite images is needed to investigate the impact of human activities on the plant cover in the WRPA.

Interests in Conflict

The authors state that the publication of this work does not include any conflicts of interest. Furthermore, the authors have carefully considered ethical problems, such as plagiarism, informed consent, misconduct, data fabrication and/or falsification, multiple publishing and/or submission and redundancy.

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