Assessment using remote sensing and GIS methods: A case study in Skeiðarársandur, Iceland

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ABSTRACT

The environmental global problem of land degradation seriously harms human existence and development. In some areas seasonal floods deliver valuable topsoil and nutrients to farmland and bring life to otherwise infertile regions of the world. In contrast, flash floods and large floods are responsible for more deaths than tornadoes and hurricanes combined. Many plants that are food resources for animals can be destroyed by flood water by being dislodged, battered or suffocated from soil inundation. In Iceland, catastrophic floods are associated with volcanic eruptions beneath the glaciers. In locales where larger volumes of sediment are flushed from beneath glaciers, they are instrumental in creating outwash plains or sandur. Often the vegetation suffers as a result of sedimentation and dislocation. The aim of this study was therefore to assess the impact of the 1996 flood on the vegetative cover in the Skeiðarársandar area and to determine its current state of recovery. One Landsat image from 1990 and one SPOT image from 2006 were used to produce a SAVI map. The results suggested that there were no serious set-backs in vegetative cover, excluding two areas in the north-eastern part of the sandur, just below the glacier ice cap. Proper field investigation is required to assess the exact influence of the flood on vegetation and soils.

Keywords: SAVI, Floods, Vegetation degradation, SPOT, Landsat, Iceland

1. INTRODUCTION

1.1. Flood impacts

The environmental global problem of land degradation, which seriously harms human existence and development, includes soil erosion, desertification, salinization or alkalization, reduced crop nutrition and organic substance wastage, soil structure degradation and pollution caused by wind, water and other factors (e.g. Changyao *et al.*, 1991). Floods have been an integral part of the human experience since the beginning of agricultural practices when the first permanent settlements were built along the river banks of Asia and Africa (Felipe *et al.*, 2006).

Seasonal floods deliver valuable topsoil and nutrients to farmland and bring life to otherwise infertile regions of the world. In contrast, flash floods and large floods are responsible for more deaths than tornadoes and hurricanes combined (Felipe *et al.*, 2006). Many plants that are food resources for animals can be destroyed by flood water by being dislodged, battered or suffocated from soil inundation (Westbrooke, 2005).

In the United States alone, over the past 60 years, flooding has resulted in the deaths of hundreds of people and billions of dollars in damage (Weier, 1999). In China and India, annual flooding along the Yellow, Yangtze, and Brahmaputra river systems has resulted in significant loss of life and property (Felipe *et al.*, 2006). Similarly, seasonal floods in the Namibian Caprivi flood plain cause regular destruction of crops leading to the need of local inhabitants to rely on government flood and drought relief (UNICEF, 2004). In north-western Europe, floods are a social and economic problem as they cause danger to both down-stream community and infrastructure.

Natural causes of flooding range from monsoonal rainstorms, tropical storms, tsunamis, hurricanes, snowmelt, extra-tropical cyclone activity, and tidal surges to failures of manmade and natural dams (Felipe *et al.*, 2006; Westbrooke, 2005). In Iceland, the biggest floods are associated with volcanic eruptions beneath the glaciers. According to Gomez *et al.* (2000), glacier outburst floods, or jökulhlaups, have generated some of the largest known terrestrial freshwater flows. In locales where larger volumes of sediment are flushed from beneath glacier, they are instrumental in creating outwash plains or *sandur* (Gomez *et al.*, 2000). While destruction of infrastructure by these floods is often experienced, the state of the vegetation also suffers as a result of sedimentation and dislocation.

Several methods are being used to assess vegetation change. These methods include expert opinions, field and field monitoring, productivity changes, and sample studies at the farmer level, modelling and remote sensing (Snel and Bot, 2003). This study used a satellite-based remote sensing method to investigate vegetative change in the Skeidarársandur area in Iceland that was subjected to a large scale flood in 1996.

1.2. Remote sensing and detection of change in vegetation

Remote sensing is defined by Lillesand and Kiefer (1987) as the science of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with object, area, or phenomenon under investigation. Remote sensing has been determined to be a cost-effective approach to document changes over large areas and even geographic regions and it has been of immense help in monitoring the changing pattern of vegetation (Lunetta *et al.*, 2004).

The use of remote sensing techniques has great advantages because of their characteristics in the application to monitoring, evaluating and forecasting any change in vegetation. By using remote sensing techniques, the user can grasp the present situation, evaluate processes such as land degradation trends in macroscopic range, and also provide a scientific basis for the prevention and administration of vegetative change.

Change detection as defined by Hoffer (1978) means revealing any changes in temporal effects such as variation in spectral response and involves situations where the spectral characteristics of the vegetation or other cover type in a given location change over time. Singh (1989) described change detection as a process that observes the differences of an object or phenomenon at different times.

Many change detection techniques have been developed to detect vegetation change using remote sensing data (Cakir *et al.,* 2006). However, despite the wide diversity of algorithms currently available, all of these techniques can usually be separated into two main categories: post-classification spectral change detection and pre-classification change detection.

Post-classification methods involve the independent thematic classification of two different images taken on two different dates. Thematic maps are then further compared and analysed to map any types of changes uncovered (Jensen, 1996). Pre-classification spectral change detection involves the analysis of transformed images from two different dates.

The transformation of different date images is the product of several specialized operations, among them multi-date image differencing, principal component analysis (PCA), normalized difference vegetation index (NDVI) differencing, etc. The transformed image contains spectral information about the changes taking place within the imagery, which then requires further processing to develop thematic change maps.

NDVI differencing is one of the most commonly applied pre-classification change detection techniques (Cakir *et al.*, 2006; du Plessis, 1999; Niipele and Klintenberg, 2007). It utilizes NDVI images in which vegetated areas are spectrally enhanced using ratios or differences between red and near-infrared bands within an image by taking advantage of the different absorbance and reflectance characteristics of the vegetation in those bands (Jensen, 1996). Areas of change can be indentified through the subtraction of the NDVI image of one date from the NDVI image of another date.

In the resultant NDVI difference image, changes can be detected at the lower-end and higher-end tails of the NDVI difference-image pixel distribution histogram. However, several studies (Klintenberg *et al.*, 2007; Cakir *et al.*, 2006; du Plessis, 1999) have shown that NDVI techniques produce limited discriminating abilities in areas less dominated by vegetative ground cover types. According to Klintenberg *et al.*, 2007, the NDVI index does not give a correct reflection of green biomass when green canopy cover is lower than 30%. Due to the normally sparse to very sparse ground cover in these areas, the underlying soil influences the spectral signature to such an extent that it has to be compensated for (Huete, 1988). For this reason, the soil-adjusted vegetation index (SAVI) has been developed. The SAVI is based on the idea that, depending on the vegetation cover, the NDVI for different cover conditions does not converge at the same location. Therefore an L-factor is used to adjust the NDVI so that different vegetation densities will intersect the soil line at the same location. This study used SAVI-based methods to detect vegetation change in the Skeiðarársandur flood plain following the 1996 jökulhlaup flood event.

1.3. Problem statement

In Namibia, flooding due to upper stream heavy rainfall is a regular occurrence. These floods not only pose a threat to the people but they also destroy crops leaving people with less food until the next harvesting season. Moreover, many hectares of natural grazing range lands are also affected.

Although there are emergency measures in place to monitor and assess the severity of these floods, there is often inadequate capacity to carry out these tasks (UNICEF, 2004). This project is therefore aimed at demonstrating remote sensing techniques that could be used to assess and monitor flood events in one's own country. The data and the project results may also be a useful tool to the Soil Conservation Service staff for monitoring vegetation changes and to aid in assessing land for restoration efforts in Iceland.

1.4. Objective

1.4.1. Overall objective

The overall objective of the project is to assess the impact of the 1996 flood on the vegetative cover in the Skeiðarársandur area and to determine its current state of recovery.

1.4.2. Specific objective

More specific objectives can be defined as:

a) Producing an NDVI map of the area.

b) Determining vegetation dynamics in the area, in terms of increase, decrease, or no changes in vegetative cover.

c) Building the author's understanding and capacity in the use of remote sensing in a project such as this.

1.5. Study site

1.5.1. Study area description

At 1352 km^2, Skeiðarársandur (Fig. 1) is a large glacier outwash plain located in South Iceland (Kofler, 2004). It is believed to be the world's largest active glacier outwash plain (Gomez *et al.*, 2000). The sand plain is formed by jökulhlaups when massive melt water floods emerge through numerous volcanic eruptions (Magilligan *et al.*, 2002, Laurence *et al.*, 2005). From September 30 to October 13, 1996, a large sub-glacial volcanic fissure eruption melted through 500–750 m of the overlying ice cap. This eruption caused accumulation of 3.6 km^3 of water that subsequently became a record jökulhlaup that flowed sub-glacially for 50 km beneath the Skeiðarárjökull Glacier before breaking onto Skeiðarársandur (Laurence *et al.*, 2005).

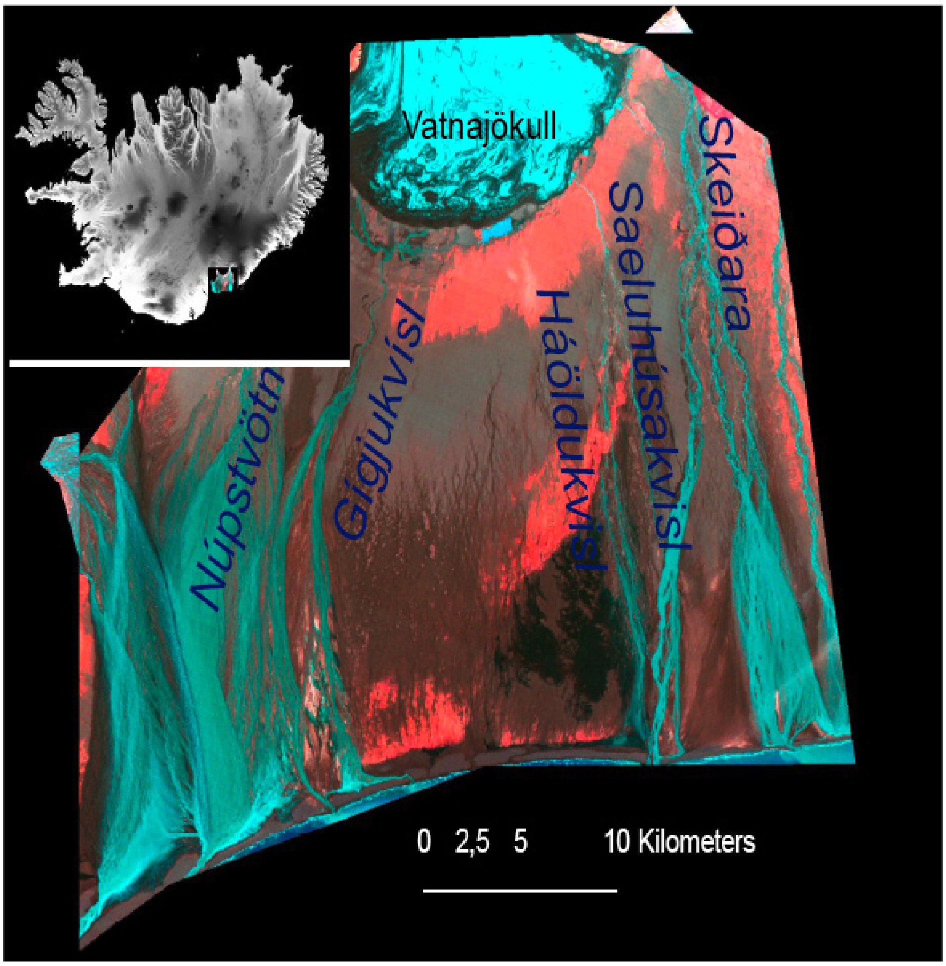

Fig. 1. *Map of Skeiðarársandur, showing the study area between the two rivers, Núpstvötn on the west and Skeiðara on the east.*

The size of the study area is about 758 km^2 and is located between the two rivers Skeiðará and Gígjukvísl and extends from the coast to the front end of the glacier. The distance from the glacier's edge to the sea is between 20 and 30 km. Skeiðará River runs from the glacier margins directly to the sandur, whereas, Gígjukvísl is fed by melt water from the central section of the Skeiðarárjökull which collects in the proglacial zone before being routed on to the sandur. The coastline is about 40 km long (Kofler, 2004). The elevation ranges from 0 to 150 meters near the Skeiðarárjökull Glacier.

1.5.2. Climate

The mean summer temperature recorded at the IMO station at Fagurholsmyri (on the east edge of Skeiðararsandur) during 1961-2001 was about 10.3˚C, while the winter mean temperature during the same period was about 0.1˚C (Kofler, 2004).

1.5.3. Soils

Gravel and sand cover large parts of Skeidararsandur with soil particles varying considerably in size. There appears to be a gradient from the glacier to the sea with the coarser particle sizes near the glacier and finer materials near the coast (Magilligan *et al.*, 2002; Kofler, 2004). This sand is mostly basaltic and is of volcanic origin, either deposited as volcanic ash or reworked by physical weathering of volcanic rocks by glaciers and other physical factors (Arnalds *et al.*, 2001).

1.5.4. Jökulhlaups

Skeiðararsandur has been formed by jökulhlaups, a relatively frequent phenomenon caused by continuous melting from the Grímsvötn geothermal area. The jökulhlaups have been occurring in the area since the 12th century. The flood in 1996 was the first big jökulhlaup since 1938 and its geomorphic situation before and after was well documented (Gomez *et al.,* 2000; 2001; 2002; Magilligan *et al.*, 2002).

2. MATERIALS AND METHODS

2.1. Images used for change detection

One Landsat image and one SPOT image were used for vegetation change detection in this study. The Landsat image was acquired in 1990 and the SPOT image was acquired in 2006. The two Landsat images both had a spatial resolution of 30 by 30 meters, whilst the SPOT image had a spatial resolution of 10 by 10 meters. The images were provided by the Icelandic Soil Conservation Service (SPOT image) and Agricultural University of Iceland (the Landsat image). The Soil Conservation Service GIS vector data source was also used. Other materials include GPS points during field verification, maps of the area, ArcGis software and, in addition, Erdas Imagine software for remote sensing applications.

2.2. Geometric correction and cloud cover

The Spot image was obtained as geometrically corrected, whereas the Landsat image was not, and thus needed to be geometrically corrected. For this reason the SPOT image was used as reference image to rectify the Landsat image. Using the Erdas Imagine program, approximately 30 ground control positions, taken from the SPOT 2006 image, were used to rectify the Landsat image. The polynomial second order geometric registration method was used. The geometric registration accuracy (root mean square) was within one pixel. No additional radiometric corrections were applied (Erdas imagine 9.1). Although both images had cloud cover, the study area was free of clouds.

2.3. Subset of the image

The two images were reduced to cover only the area of Skeiðararsandur and also to be generally the same size. This eliminated unnecessary data amounts, which also speeds up processing.

2.4. Calculation of vegetation change detection

The soil adjusted vegetation index (SAVI) was calculated from data from the two satellite images (Landsat 1999 and SPOT 2006) using the Erdas Imagine image processing software. It was defined as: **SAVI = (NIR-R)/NIR+R+L)*(1+L)**, where **NIR** stands for near-infrared, **R** stands for red and **L** stands for soil cover. An L factor of 0.5 was used, as suggested by Huete (1988). The resulting SAVI image, calculated using both the Landsat and SPOT images, had a range of -1 to 1 real data (Jensen, 1996). This SAVI image was used to obtain a vegetation cover map showing the area that had increased, decreased or exhibited no change in vegetation cover. Using the ArcGis program, and a 1 standard deviation classification, the vegetation change cover map was produced.

The Landsat and SPOT images used in the study were from two different satellite sensors, thus had different pixel resolutions. Landsat had a pixel resolution of 30 m by 30 m, while the SPOT image had a pixel resolution of 10 m by 10 m. The difference in resolution might have affected the result as the low Landsat pixel resolution might have resulted in an increase in the SAVI when actually no change in vegetation could have taken place. Furthermore, some areas were wet, making it difficult to tell the actual effect. These areas were therefore masked out of the study data in order to avoid their effect on the results.

2.5. Field verification points

About ten GPS points were picked from the SAVI map and saved in the GPS equipment and these points were used during one day of field ground observation to ascertain the accuracy of the produced map. The knowledge gained in the field was then used for the interpretation of results.

3. RESULTS AND DISCUSSION

3.1. Results

The results recorded areas where the vegetation cover had increased. However, there were areas where there was little or no change in the vegetatation cover as well as areas where the vegetation cover had decreased.

The SAVI composite map (Fig. 2) revealed that areas with increase in the vegetation cover lay in the south-east corner of the study area, forming a linear horizontal section along the eastern coast. Other sections with an increase in SAVI include south-central region, forming a vertical linear (northern linear) trend that ends in the south-eastern half. The northern part showed areas with an increase in SAVI. These were areas just north of the main road, on the northern part of the map, stretching from the west to the top eastern corner. However there were also patches with a high SAVI value scattered around in the western central areas.

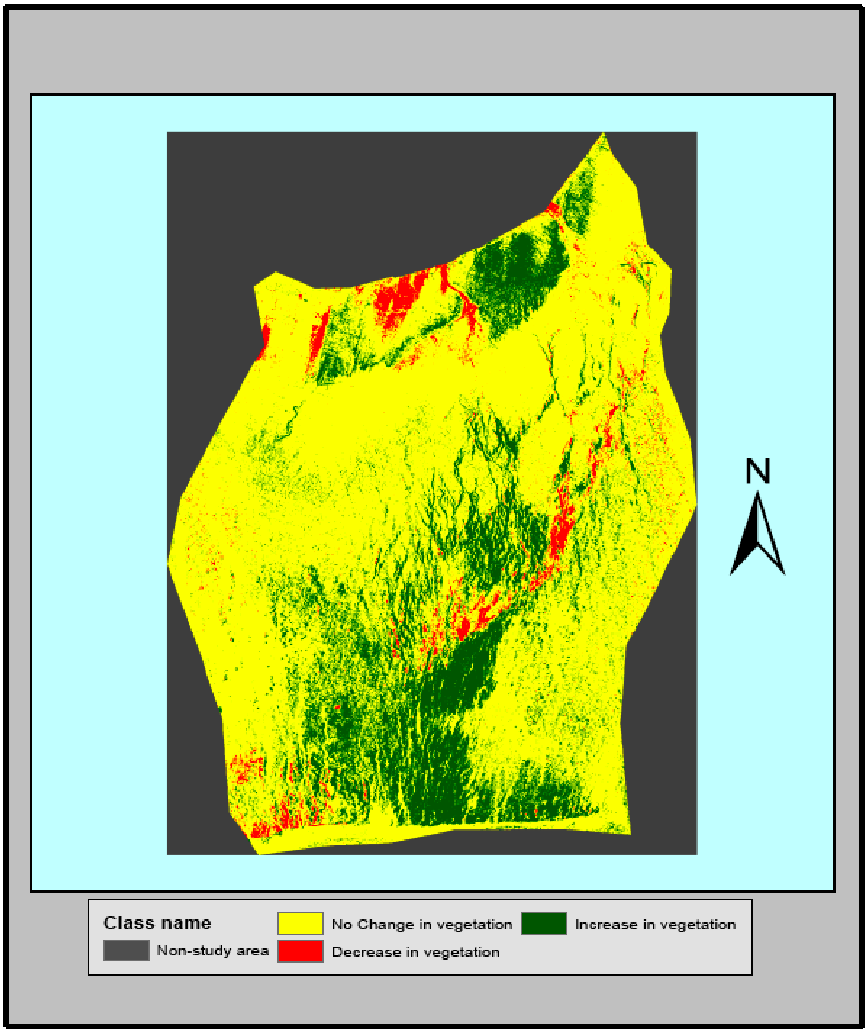

Fig. 2. *Map showing results of the SAVI (1 standard deviation) image differencing of Landsat image from 1990 and SPOT image from 2006. The green to light green are areas that recorded increase in SAVI, blue area areas with no change and red to yellow represent areas with decreased SAVI.*

Areas with little or no increase in vegetation increase are represented in blue, a belt stretching west to east. Other areas were found in the northern upper part off the main road, on the north-west and at the northern top, just south of the brown areas. Areas that recorded a decrease in vegetation cover included the square sections in the south-western corner and areas forming a vertical linear line around the east-central areas. Other areas that recorded decreases in SAVI are found on the northern half of the map, just below the glacier cap.

In total an area of about 33647 hectares was assessed in the study. The results showed that 26488 of hectares did not show a change in vegetation, while 6154 hectares recorded an increase in vegetation and only 1005 hectares recorded a decrease in the vegetation (Fig. 3).

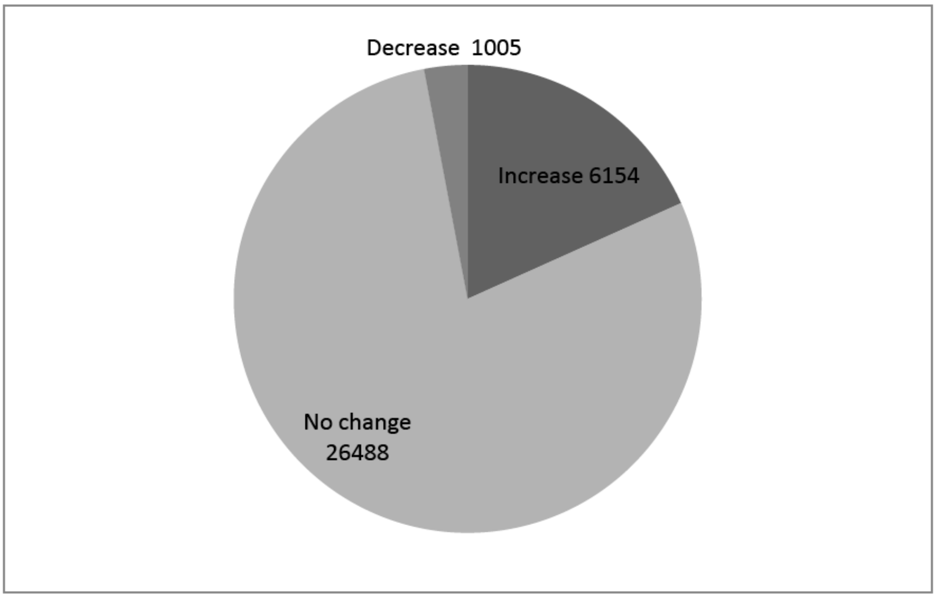

***Fig. 3**. A pie chart showing proportion of areas in hectares (ha) with increase, decrease and no change in SAVI.*

3.2. Discussion

Although the major flood in 1996 may have affected the vegetation negatively, the analysis of the satellite images revealed that the changes during the study period were both negative and positive. There were areas that clearly lost the previous vegetation cover and areas that had gained in vegetation cover. The younger satellite image clearly revealed those areas that recorded an increase in vegetation cover. The increase in vegetation in these areas could be attributed to their location within the flooded zone. It appears that these areas lie at the edge of the flooded areas, suggesting that most likely the flood water was ran only slowly there, thus leading to a favourable vegetation response due to the fact that the flood brought mineral rich water and sedimentation. The vegetation type in this area contained patches of *Leymus arenarius*, other grasses with patches of low moss growth on a rather moist sandy landscape. Alternatively, favourable moisture conditions made these systems resilient to the relatively mild flooding in these areas.

The areas along the main road and the area north of the main road that recorded an increase were found on a medium dry gravel sand surface with high density growth of green moss and some patches of individual birch shrub. There were also a few other grass species. The flood data showed that the whole area north of the main road (Fig. 4) was flooded, while the area south of the main road was flooded up to a distance of about 1.5 km from the main road. Taking this into consideration, it could mean that the same sedimentation process as explained above could have benefited the vegetation. These results also correspond with the vegetation classification by Kofler (2004), who produced similar vegetation cover maps.

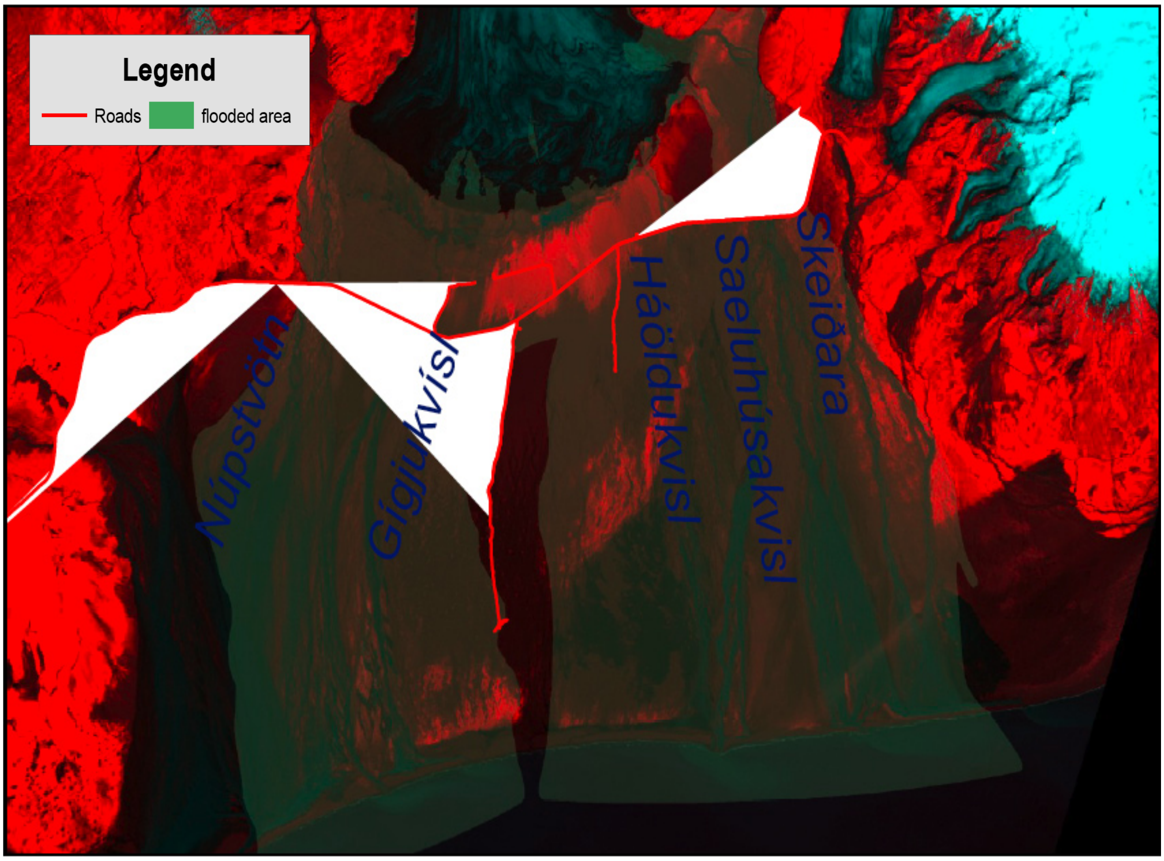

Fig. 4. *Map of showing areas affected by the 1996 Skeiðarársandur catastrophic flood.*

The areas that recorded no change in SAVI were those mostly located south of the main road. No change in SAVI in these areas could be explained by the gravelly and dry nature of the landscape. However, some areas showed an increase in SAVI, but it appears that the Landsat sensor's spatial resolution rather than an actual increase in vegetation has led to some areas showing an increase in SAVI. These were areas with patches of *Leymus arenarius* plants. This could have been because some patches of grass were too small to reflect strongly in the Landsat image but reflected strongly in the SPOT image due to its high spatial resolution. This could suggest that if the same satellite sensor was used in the SAVI analysis, these areas could have appeared not to have changed.

Areas that recorded a decrease in the SAVI were located in the south-west corner of the study area, the central south-east sector and the eastern side as well as the northern upper part of the study area. The decrease in the south-western corner could be directly attributed to the flooding due to its close proximity to the heavily flooded area. The intensity of the flood might have caused severe destruction in this locality. The erosional effects of the flash floods might have been extensive and included the expansion of the stream channels, mass movement, and the almost complete removal of vegetation in broad strips along the water courses (Kofler, 2004).

The decrease in SAVI in the south-central to north-eastern strip could also be attributed to the flooding. The outburst flood water from the Saeluhúsakvísl river channel in this area was split in two, with one channel joining the flood water from the Háöldukvísl overflow channels (Gomez *et al.,* 2000). This mass movement may have removed surface materials, resulting in this linear decrease of vegetation cover. The same situation appeared to have prevailed in the section that showed a decrease in SAVI in the north-western part of the study area. The area is near the narrow notch of the Núpsvötn channels; therefore flood water may have escaped into smaller channels, further increasing their flooding intensity, thereby causing severe damage to the vegetation. The visual investigations of the two satellite images showed a dark plain area just east of Núpsvötn in the second image (Spot 2006), which otherwise was vegetated in the first image (Landsat 1999).

The decrease in vegetation in the area on the northern part just below the glacier ice cap could be attributed to sand encroachment, as field visits revealed signs of sand blasting with moss vegetation clearly in retreat due to the sand front pressure. The origin of sand is the area fronting the Vatnajökull Glacier. When the glacier receded in a warm climate, it exposed large areas and a sandur was created (Arnalds, 2001). The other areas just east of it appeared to have sand encroachment problems.

The advancing sand fronts as explained by Arnalds *et al.* (2000) and Arnalds (2008) are active tongue-shaped sandy surfaces extending into vegetated areas. These fronts start as sedimentary features (encroaching sand) that abrade and bury the vegetation with sand and destroy it.

4. CONCLUSION AND RECOMMENDATIONS

From the SAVI analysis results it could be concluded that although some areas recorded a decrease in vegetation, there are also areas that had had an increase in vegetation since 1990. This suggested positive as well as negative changes. These changes could be attributed to many factors, among them the 1996 catastrophic flood, but there are several other factors that could have affected the vegetation, such as warmer climate, rain sink, sand encroachment. From the results, although there were areas that recorded a decrease in vegetation cover, generally it appeared that there were no serious set-backs in vegetation, excluding two north-east areas just below the glacier ice cap. These two areas, one in the water channel and the other the surrounding area, are bare of cover, probably due to excess flooding. However, more extensive field investigation beyond that covered in this study is required to assess the exact extent of the influence of the flood.

ACKNOWLEDGEMENTS

I would like to thank the Agricultural University of Iceland through the LRT programme and the Icelandic government for affording me this opportunity to enhance my scientific knowledge and ability. The government of the Republic of Namibia allowed me to be absent from work for this long, and for this I am grateful and will always be available to serve my country. I am grateful as well to my colleagues in the Directorate of Forestry who covered for my duties. The LRT project manager, Dr Ingibjörg S. Jónsdóttir, and her Assistant Project Manager, Dr Hafdís Hanna Aegisdóttir, ensured that our stay in Iceland was worthwhile and that our daily needs were addressed, and for this we are very thankful. To the staff at Keldnaholt campus and all lecturers for the modules, thanks all for your shared experience. The Soil Conservation Service provided field exposure, accommodation, and of course good regular meals - for this I am grateful. The contribution and regular guidance of my main supervisor, Sigmar Metusalemsson, were immeasurable. Dr Ólafur G. Arnalds gave valuable comments and guidance on writing up this project., I am also indebted to Johann Thorarensen for his help in the field and also with the ArcGis programme. To my fellow LRTs, thanks for the knowledge and time shared together.

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ISBN 978-9979-70-625-0