Wind Erosion Mapping and Monitoring in the Central Rift Valley of Kenya Using Small-Format Aerial Photography (SFAP)

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Abstract: A field study was carried out in the central Rift Valley of Kenya to map and monitor wind erosion features using small format aerial photography (SFAP. The use of SFAP proved in spite of some minor operational draw-backs to be quite promising in terms of geometric accuracy, visual quality, cost effectiveness and above all timeliness. Generation and application of SFAP allowed for a detailed assessment of the current erosion status followed by a spatio-temporal GIS analysis of wind erosion patterns and trends in relation to some key environmental factors.

Keywords: wind erosion, mapping and monitoring, small format aerial photography (SFAP), GLASOD, volcanic soils

1 Introduction

Over the past two decades the semi-arid rangeland zone around Lake Naivasha in the central Rift Valley of Kenya has come under severe human pressure. Main causes are the steady encroachment into the area by smallholder farmers coming from higher parts of the Rift Valley, and the subsequent reduction of grazing land left for the Maasai pastoralists (Ataya 2000). These developments have lead to overgrazing followed by severe wind erosion, which has now become a major threat to the livelihood of many inhabitants of the rangeland zone.

Accurate analysis of wind erosion problems appeared to be impossible due to the overall lack of up-to-date, high-resolution remote sensing data of the affected area. This included the absence of recent aerial photographs, and although up-to-date satellite imagery (TM-Landsat 1995 and 2000) was available for the rangeland zone, their general spatial resolution proved to be far too low for accurate mapping and monitoring of the prevailing wind erosion patterns. It was therefore decided to apply small format aerial photography (SFAP) in order to achieve the required analysis. A special study was designed with as main objective to map and monitor wind erosion features using SFAP as a complementary tool to conventional aerial photography. Specific study objectives included (1) analysis of SFAP performance in terms of geometric accuracy and resource & cost effectiveness, (2) analysis and mapping wind erosion features, (3) assessment of current wind erosion status, (4) monitoring of wind erosion rate and (5) analysis of spatial relationships between current erosion status and trends with underlying erosion factors.

2 Description of the study area

The study area is situated in the central part of the Kenya Rift Valley, southeast of Lake Naivasha, about 70 km northwest of Nairobi. The area lies at an altitude of around 2,100 m a.s.l. and covers about 370 ha. It is bounded by latitudes 0°49′S to 0°53′S and longitudes 36°27′E to 36°29′E and, administratively, falls under the Naivasha Division of Nakuru District. The area has a semi-arid to dry sub-humid, cool tropical highland climate. Mean annual rainfall ranges between 600 mm/year—700 mm/year. Mean minimum and maximum monthly temperatures vary between 15.9°C to 18.5°C and from 24.6°C to 28.3°C, respectively. The long rainy season is from March to May with the short rainy season from October to December. Mean monthly wind velocity is highest in the period April-September (6 m/s—7 m/s) and lowest during November-February (3 m/s—4 m/s). Mean maximum wind speed is considerably higher and may reach up to 15 m/s—20 m/s during May-August resulting in high erosivity levels of the predominantly easterly winds during this period. The natural vegetation of the area mainly consists of low *Acacia* shrub grassland with *Acacia drepanolobium* (“Whistling Thorn”) as main woody species and *Themeda triandra* as the dominant grass. Since the 1980s, however, most of the natural vegetation has been cleared or degraded into grassland. Current land use is mainly nomadic pastoralism with some marginal arable farming on small isolated farms, remnants of the smallholder settlement schemes that were abandoned in the early 1990s.

3 Methodology

The generation of an adequate SFAP coverage of the study area requires careful planning. Fig.1 presents a flow-chart indicating the key parameters and successive steps required to determine the following : (1) number of flight lines, (2) number of photographs per flight line and (3) total number of SFAP photographs to be taken for a specified area, at the photo scale required.

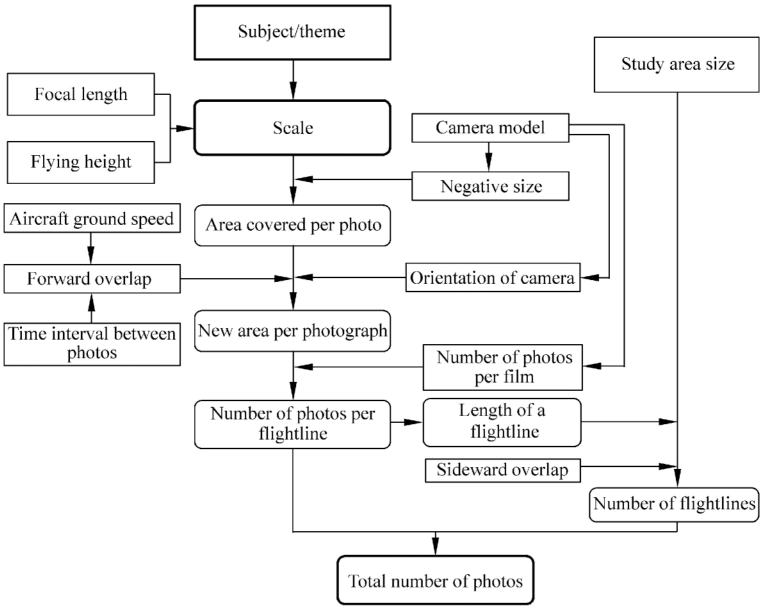

Fig.1 Flow-chart showing key parameters in planning (1) number of flight lines, (2) number of photographs per flight line and (3) total number of SFAP photographs for a specified area and required photo scale

To calculate above parameters, a simple spreadsheet in EXCEL was used. The following predefined equipment-related parameters were entered: focal length (35 mm), photo negative size (standard 24 mm×36 mm) and ground speed (140 km/h). Other parameters such as flying height, depression angle and forward overlap were defined rather by the objectives of the study itself. Flying height, for example, is partly depending on photo-scale required. As the study of wind erosion features needs detailed photographs of scale of 1:5,000 on a 10 cm×15 cm photo-format, required flying height was determined at 2,300 feet above terrain. Further, stereoscopic analysis demands a forward overlap of at least 50%. From these predefined parameters the area covered per photograph, total photographs and time interval between photographs could be obtained using the above EXCEL spreadsheet. Five N-S parallel running flight lines were required to cover the reconnaissance area. Three coordinates of each flight line were entered in the GPS (Garmin III) of the aircraft. The first point, around 4 km before entering the study area, was essential to position the aircraft so that it can enter the flight line in a straight way. To start and finish photographing, the first and the last point of the flight line above the reconnaissance area were also entered in the GPS. An important advantage of the Garmin III proved its capability to display the complete route (flight lines) including the position of the aircraft, so that during the flight small deviations from the flight course could be corrected.

The SFAP photographs were taken with a Minolta X7000 AF camera (35mm) from a small Cessna 182 aircraft; a total of 130 photographs were shot covering the reconnaissance area following a carefully planned flight plan. From the above 130 photographs 28 photographs covering the actual pilot study area were finally selected for further analysis. A quality check was first done on the GPS-observations for ground control. During the field phase for each photograph around 20 GPS (Garmin 12) observations of 5 min were made to obtain ground control points to rectify the images.

A photo-interpretation was then made of the pilot area using both old conventional aerial photographs of 1991 (1:20,000) and the new SFAP colour prints (1:5,000). During the field phase the prevailing soil pattern in the study area in combination with land cover and degradation features was systematically examined and mapped. This generated a geo-pedological map and two land cover/degradation maps, one for 1991 and one for 2000. To assess current status of land degradation in the area, the different erosion features were grouped into severity classes using an adapted version of the GLASOD methodology (Oldeman *et al*., 1991). From the erosion severity maps of the two different periods, general trends and rate of land degradation for the period 1991—2000 could be calculated and assessed through standard GIS analysis using ILWIS. Finally, a spatio-temporal analysis was made of the main causal factors underlying the wind erosion patterns in the study area.

4 Results and discussion

4.1 Analysis of SFAP performance

(1) Geometric aspects

The study showed that for a pilot area of 370 ha an up-to-date and adequate SFAP photo-cover at a scale 1:5,000 can be generated within a remarkably short time of about two weeks. The visual quality of the SFAP images ranged from good to excellent allowing for quick detection and detailed analysis of wind erosion features and other land degradation-related phenomena; height differences of less than 1 m appeared to be readily detectable on the SFAP image. Main operational constraints included adverse weather conditions prior to flying (cloudiness) and during the flight (wind gusts), the latter in combination with the low speed as required and the low weight of the aircraft itself. GPS quality testing using established benchmarks yielded surprisingly good results with 85% of the observations within 6 m from the benchmark. Camera position analysis showed general inclinations between 0.1° and 5°. When these values are matched with the accuracy limits used in conventional photography (< 3°), almost two-third of the SFAP images appears to fall within the acceptable range.

Around 20 ground control points were obtained for each SFAP photograph. Each observation showed an distinct error but in the rectification process observations with considerable horizontal errors were quickly detected as their Sigma/RMS is very high. Table 1 gives a general overview of the active control points and the corresponding sigma's in the rectification process. The overall sigma after rectification is low. Multiplying sigma value with pixel size gives errors ranging between 1.0 m up to 2.1 m, with a mean of 1.4 m per photograph. These values fall within the error range of the GPS (Garmin 12) recordings as indicated above.

Table 1 Sigma values before and after correction, pixel size and calculated error per SFAP photo (projective transformation)

SFAP number	GPS points measured	Sigma with all GPS points	Active control points	Sigma after correction	Pixel size (m)	Error (m)
B00	14	7.58	9	2.36	0.41	0.97
B01	20	8.36	14	4.93	0.43	2.12
C18	19	4.80	14	3.26	0.50	1.63
C20	20	7.18	14	3.05	0.49	1.50
C22	24	5.79	17	2.78	0.48	1.34

(2) Manpower and cost efficiency aspects

Table 2 presents a general overview of the number of man-days and costs (US$) for the different flight and fieldwork operations to obtain a wind erosion status map of the study area (370 ha). In total, 13 working days were needed to cover an area of around 370 ha, 2.5 days for flight preparation and obtaining the photographs, 5 days of fieldwork and 5.5 days office work. However, this does not mean that the job was done in just two weeks: Between planning for the flight and the flight itself, almost two weeks were lost due to prohibitive (cloudy) weather conditions. In terms of delivery time SFAP compares quite favourably with conventional aerial photography which only in exceptional cases can deliver a similar output in such a short period. Also, overall costs for SFAP generation are minimal when compared with conventional aerial photography. For the study area (3.7 km^2) and the total reconnaissance area of 15.3 km^2 (both at scale 1:5,000) costs were US $ 76 and US$ 20 per km^2, respectively. These values are only 25% and 7% of the photo costs (US$ 300/km^2) incurred by an urban cadastral project in Bolivia using conventional photographs of a comparable scale (1:4,000).

Table 2 Number of man-days and costs (US$) for the various flight and fieldwork operations and materials to map an area of 370 ha

SFAP operations and materials	Number of Man-days	Costs (US$)
Flight preparation	1.0	
Films & developing of photographs	1.0	60
Execution of flight	0.5	220
Collecting of GPS points (180)	3.0	
Interpretation of photographs (14) and collecting wind erosion data	4.0	
Scanning and georeferencing of photographs	1.5	
Digitising and compilation of final map	2.0	
Total resource use (370 ha)	13.0	280
Resource use efficiency in man-day / km^2 and in US$ / km^2	3.5	75.7

4.2 Analysis and assessment of wind erosion

(1) Soils and landscape

The study area forms part of the central Rift Valley floor and consists largely of a gently sloping Volcanic Plain landscape covered with stratified volcanic ash deposits from the nearby Mt. Longonot volcano. The Volcanic Plain is almost entirely covered by young, poorly developed coarse-textured soils derived from Pleistocene Longonot ash and Akira pumice deposits. The soils generally consist of very deep, excessively drained, very friable, brown loamy sands and sands (Ah and Bw horizons) overlying a succession of dark grey and whitish grey, loose fine ash and pumice gravel layers (C-horizons). Three geopedological map units were distinguished on the basis of micro-relief consisting of low knolls (representing fossil dunes) : Pv111—Volcanic Plain without knolly micro-relief, Pv112 — Volcanic Plain with low knolly micro-relief (0.5 m — 2.0 m) and Pv113—Volcanic Plain with moderate knolly micro-relief (2.0 m — 4.0 m). Above soils classify as *Areni-Vitric Andosols (Dystric)* according to the World Reference Base classification (FAO 1998) on account of their sandy texture, relatively high content of volcanic glass in the fine earth fraction, and low base saturation in the control section. The soils are subdivided on the basis of (1) thickness of the relatively coherent Bw horizon, and (2) presence and depth of loose, highly erodible sandy ash layers in the lower subsoil (C-horizon). Three soil phases with increasing vulnerability to wind erosion could thus be distinguished in the study area :

Soil phase A : thickness Bw horizon. < 50 cm, immediately overlying pumice gravel layers

Soil phase B : thickness Bw horizon > 50 cm immediately overlying loose fine ash layers

Soil phase C : thickness Bw horizon < 50 cm immediately overlying loose fine ash layers

(2) Classifying and mapping of wind erosion features

The excellent visual quality and large photo-scale of the SFAP images allowed for a sound analysis and interpretation of the various wind erosion features. Detailed photo examination revealed the occurrence of a peculiar wind erosion pattern in the southern and central parts of the study area. This pattern comprises clusters of ENE-WSW running strips each consisting on its weather-side of a “head”, in the form of an oval to gully-shaped blow-out depression and a fan-shaped depositional rear or “tail” on its lee-side (Fig. 2). The morphology of the blow-out depressions (wind erosion subtype D covering 0.5% of study area) is variable depending on their stage of development. Shape and size may range from oval, shallow depressions of only a metres long and wide at an early stage of development to massive deflation trenches of up to 150 m long and over 25 m wide in a mature stage. Depth of the blow-out depressions generally varies between 0.5 m—4.0 m. Shallow blow-out depressions appear to be carved out into the Bw-horizon showing a brownish colour on the SFAP photo-image; Mature deflation trenches have cut through the lower subsoil into the underlying whitish to dark grey ash strata thus showing grey on the photo-image. The depositional areas or sand sheets (wind erosion subtype S covering 5.1% of study area) are mostly associated with one particular blow-out depression. The thickness of the sand sheets ranges from a few centimetres to over 50 cm. For the purpose of mapping both wind erosion subtypes D and S have been sub-divided into 7 different classes according to actual depth of deflation (abrasion) or deposition.

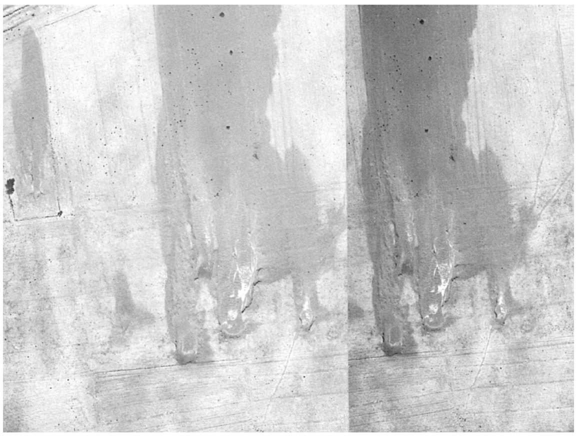

Fig. 2 SFAP stereogram showing colascing deflation trenches (approx. scale 1: 34 000)

(3) Assessment of current wind erosion status

The assessment of current erosion status has been based on the concept of soil degradation severity as defined in the GLASOD classification (Oldeman *et al.*,1991). Soil degradation severity is an aggregation of 2 dimensions : ① the degree of soil degradation (vertical dimension) and ② the extent of the degradation process (lateral dimension). The degree or intensity of soil degradation is related to observed changes in the agricultural suitability, productivity, and restoration potential and biotic functions at one particular location (Oldeman, Lynden *et al.*, 1997). The extent of soil degradation is defined as the relative frequency of occurrence of a particular type of degradation within the delineated map unit. The GLASOD classification has been applied in this study in adapted form to categorize and interpret wind erosion features mapped. Four different erosion intensity classes were distinguished in both deflation and depositional areas; class distinctions and critical levels are defined as below.

D -	Blow-out depressions (deflation / abrasion areas)
None:	No visible signs of recent erosion.
Slight:	Topsoil is partly removed exposing brown Bw-horizon
Moderate:	Topsoil and upper subsoil have been completely removed and dark grey C-horizon is exposed deflation depth < 1 m.
Severe:	Topsoil and entire subsoil have been removed and C-horizon with light and dark grey ash-layers is exposed; deflation depth ranges between 1m—4 m.
S -	Sand sheets (depositional areas)
None:	No visible signs of recent deposition.
Slight:	Depth of deposition is < 5 cm; some grasses are still present

Moderate: Depth of deposition is 5 cm — 25 cm
Severe: Depth of deposition > 25 cm

Due to the high spatial resolution, large photo scale and good quality of the SFAP images in combination with the relative spatial homogeneity of the different wind erosion features themselves, it was possible to assess and spatially present the current wind erosion status directly on the basis of above erosion intensity classes (Fig. 3). However, analysis of the spatial relationship between wind erosion occurrence and the various geopedological units requires specific additional information about the relative extent of wind erosion features in a particular map unit. This is expressed as the frequency of occurrence within the delineated mapping unit. The following frequency classes have been used : Infrequent : < 5% of the map unit is affected; Common : 6% to 10% of the map unit is affected; Frequent : 11% to 25% of the map unit is affected ; Very frequent : 26% to 50% of the map unit is affected and Dominant : > 50% of the map unit is affected. To obtain wind erosion severity classes for the area, a 2D-matrix table was used combining erosion intensity and frequency classes into integrated erosion severity classes (adapted from (Oldeman and van Lynden 1997)). When applied to the three main geopedological map units in the study area, Pv111, Pv 112 and Pv113, it appears that the latter unit is most severely affected (12.6 % in the high — very high severity class), followed by map unit Pv112 (4.6 % in the high — very high severity class) and finally, map unit Pv111 (0% in the high—very high seveity class).

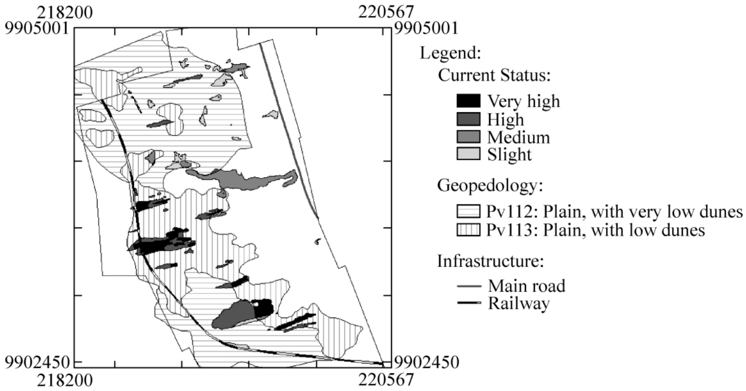

Fig. 3 Current wind erosion status of study area

(4) Spatio-temporal analysis of wind erosion

To monitor the impact of wind erosion on the area SFAP was used in combination with conventional photography to analyse surface changes over the period 1991—2001. They showed a nine-fold increase of deflation areas and a nearly twenty-fold increase of deposition areas (Table 3). In addition, it was found that gross and annual volumetric soil losses per ha in the area range between 53 m^3/ha — 64 m^3/ha and 6 m^3/（ha・year）—7 m^3/（ha・year）, respectively. Assuming an average soil bulk density of 1.3 Mg/m^3, total and annual soil weight losses from the area are estimated at 69 Mg/ha-83 Mg/ha and 8 Mg/(ha・year)—9 Mg/(ha・year), respectively. For the most vulnerable map unit (Pv113) total and annual weight losses are quite considerable being 260 Mg/ha — 310 Mg/ha and 29 Mg/(ha・year)—34 Mg/(ha・year), respectively.

Table 3 Absolute and relative changes in area affected by wind erosion over the period 1991—2000

Year	1991		2000	
	Area (ha)	% study area	Area (ha)	% study area
Deflation areas (D)	0.22	0.1	1.89	0.5
Deposition areas (S)	1.14	0.3	19.00	5.1

Standard GIS analysis including map overlay revealed a strong spatial relationship between (1) severity of wind erosion and (2) the occurrence of a pronounced knolly micro-relief in the study area. This is best exemplified by geopedological map unit Pv113 which combines a high erosion severity class with a distinct knolly micro-relief. It seems likely that the presence of knolly terrain forms a key factor in the wind erosion process as wind erodibility has been found to increase sharply in areas with a distinct micro-relief (Chepil, Siddoway *et al*., 1964). An additional causal factor is the predominance of wind erodible soil phase C in this map unit. Important parameters here are the poor aggregate size distribution (high % aggregates with diameter < 0.84 mm) in combination with a low specific density of the soil, probably due to the presence of pumice in the fine earth fraction. Both soil characteristics have a strong influence on wind erodibility (Zobeck 1991). More on-site research is required on the specific relationship between wind erodibility and key mineralogical, pedological and soil physical properties of the different soils in the area. Finally, additional analysis revealed that almost all large deflation trenches are found on or near abandoned arable fields. This confirmed earlier suspicions that careless soil management in combination with cattle trampling and destruction of old farm roads has been a major contributing factor to wind erosion in the area (Ataya 2000).

5 Conclusions

The use of SFAP proves to be quite promising in terms of geometric accuracy, visual quality and spatial resolution in particular, manpower and cost efficiency and above all, timeliness. The study showed that for an area of 370 ha an up-to-date, adequate SFAP photo-cover at scale 1:5,000 can be generated within a remarkably short time (two weeks). Main operational constraints include adverse weather conditions prior to and during the flight, the latter in combination with the low speed and low weight of the aircraft itself. SFAP compares quite favourably with conventional aerial photography, particularly in terms of delivery time since the latter only in exceptional cases can deliver a comparable output within such limited periods. Finally, overall costs for SFAP generation are minimal in comparison to conventional aerial photography. Generation and application of SFAP allowed for a detailed assessment of the current erosion status in the study area followed by spatio-temporal analysis of wind erosion patterns and trends in relation to some key environmental factors.

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