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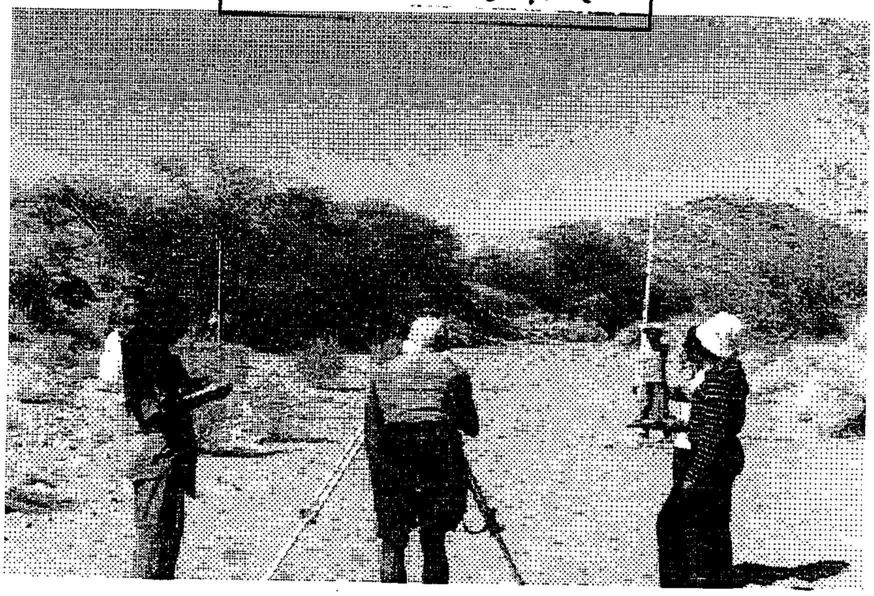
Influence of farm dams on water balance in an Ephemeral river system: The Kuiseb basin/catchment

Findings of the Summer Desertification Program 9, 2000/2001



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Influence of farm dams on water balance in an ephemeral river system: The Kuiseb basin/catchment

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Ahlert Mr

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To RC

The same people as well as

Chapter 1: Dams

J. J. T.

By: Goreseb, ~~Jefta~~, Nampila, ~~Jacobina and~~ Thomas, ~~Theopolina~~

& Telecom

Introduction

The main sources of water on farms are boreholes and dams, which are supplied via rainfall.
Dams in the Kuiseb catchment are mostly made of earth walls and in few cases reinforced by rocks and concrete walls. Earth dams are important sources of water storage. The size of earth dams mainly depends on their location in the riverbed.

Considerable losses of water from dams occur through evaporation and this is attributed to the surface area and depth of the dam, this makes planning and managing of dams very important. Earth dams are used for different purposes such as livestock, game, irrigation, domestic use and for recharging boreholes. ~~Since~~ While dams ~~seem to be this~~ are so important, the number of dams per farm and their capacities should be strictly controlled to ensure ~~sustainable management of water resources and~~ equitable access to water by all consumers in the catchment. Since all the dams in the catchment are filled by a ephemeral running river, it is important that dams in the upper catchment are of sizes that leave water to flow down to the lowest of the catchment.

Complaints have reached the Department of Water Affairs (DWA) that water reaching the lower part of the catchment is not enough. This is a serious problem and the DWA believes that the problem might be due to a proliferation of ~~huge~~ known dams, and that many new dams that are not registered might have ~~the~~ capacities greater than ~~the~~ 20,000m^3, for which the owner needs a special permit. Since the existing information on DARD and DWA files ~~has unknown correctness~~, and possibly accuracy and ~~completeness~~ completeness, it was necessary to carry out a study in order to have a better understanding of the situation.

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Surveys were carried out in two test areas, the higher rainfall area (375mm/year) and the lower rainfall area (200mm/year) of the Kuiseb catchment.
The main purpose of the surveys ~~is~~ was to obtain dam basin characteristics including depth, area and volume for the extrapolation of the whole catchment and the development of the water flow model of the entire catchment.

not clear

Methodology of Dam Surveying

Dam Surveying ~~is a method~~ was used to ~~study the~~ measure certain parameters of the dams, viz depth, surface area and capacity. ~~Techniques like~~ Leveling and the use of Global Positioning System (GPS) ~~are~~ were employed in this method.
Leveling is a technique that compares two points on the surface of the earth, whereby the height of one point ~~can be given only~~ is measured relative to another. GPS is an instrument used to determine geographical positions and map routes.

The following procedures were used to survey the dams:

a) Identification of Dams
b) Instrumentation
c) Measurement
d) Changing Instrument Position
e) Documentation

a) Identification of dams

Dams in the study area were identified using aerial photographs, and topographic maps. Some of the dams were identified using helicopter survey and observing ~~(general survey)~~ by vehicle and foot. Farmers and farm-workers also aided with giving the correct direction to the dams.

b) Instrumentation

Point leveling was used to survey dams. This requires an instrument (i.e. the dumpy level and tripod) and the staff (this is a graduated meter of about 5m in length and it should be held upright for correct measurements).

It is important to set up the instrument at a position where one can see large portions of the dam, so that one changes the position of the instrument as infrequently as possible. This helps to prevent confusion during the analysis of data.

When setting up the instrument, the tripod should stand firmly and it should not be moved or bumped against, once it is put up. The dumpy level can then be screwed on the tripod. After that the bubble on the dumpy level can be leveled using the three knobs to adjust the bubble. Only two knobs should be moved at a time, these should run parallel to the dumpy. When the bubble appears to be leveled, the two knobs are aligned perpendicular to the dumpy; this can be repeated until the bubble is always in the middle of the circle when viewed from all directions. The instrument is then leveled.

The dumpy level has a protractor, which measures the direction at which the instrument is pointing (giving the direction of the position where the reading is taken). The protractor should be set to zero degree in the beginning of the survey.

N.B The protractor should not be moved when the reading is being taken.

A person holding a staff should move to a point where the readings will be taken by looking through a dumpy level.

c) Measurements

i) Elevation

First of all, the dam wall and the dam spillway should be identified, and the measurement of the spillway should first be taken. A spillway is the lowest point of the dam wall i.e. a point where the water starts flowing out when the dam is full. *

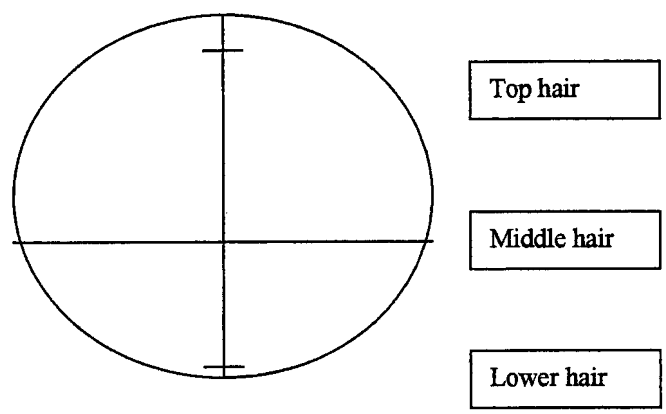
It is important to record all the readings, middle hair, top hair and lower hair readings, as well as angles of readings, make remarks on all points if possible, and to draw a rough sketch of the dam.

The Full Supply Level (a level where the dam is full to its capacity and starts to overflow.) has first to be determined from the points taken at the spillway. A terrain or ground level is assumed as 100.00 for full supply. The elevation of points throughout the dam (reduced levels) is based on reference to the full supply.

ii) Distance

The dumpy level gives the distance between the dumpy level itself and the staff.

The following diagram is what one sees when looking through the dumpy level:



It is also very important that the middle hair and one other hair (either top or lower hair, if another hair cannot be seen) is recorded as this will be used in the calculations of Reduced level/ Ground levels and the distance between the instrument and the staff. The difference between the top and the lower hairs gives the distance between staff and the instrument in meters when multiplied by 100.

Distance between dumpy level and staff = (Top hair –Lower hair) X 100

Readings of distances, degrees and ground levels are used to draw contours and to calculate the dam parameters.

d) Changing Instrument Position

When one needs to change the instrument from one position to another, two readings should be taken from current Instrument Position before moving the instrument to the new position.

For instance the current instrument position is IP_1 and you want to move the instrument to the new position, IP_2 (mark this position). First the reading to the new position is taken i.e. from IP_1 to IP_2 and then another reading is taken to a fixed position that is called a change position or control position (CP) i.e. from IP_1 to CP.
The instrument is then moved to the new position called IP_2 and the reading from IP_2 to CP is then taken.

Hint- it is better to take the IP_2 readings before the CP readings.
-The Reduced level from IP_1 to CP and the one from IP_2 to CP should be the same, as the staff is not moved.

e) Documentation

A prepared sheet for recording data is made available (e.g. below).

Table. 1 an example of the sheet for recording data

Back Sight	Intermediate Sight	Fore Sight	Collimation Height	Reduced Level	Lower hair	Top Hair	Distance (m)	Angle (Degree)	Remarks

It is very important to indicate clearly the Back sight reading (the first middle hair reading taken when an instrument is first set up or it can be the new reading of the CP taken from a new instrument position. The fore sight is the reading taken from an instrument position to the change position. All other middle hair points are recorded as intermediate sights. The readings of the top and lower hairs, and the angle must be recorded for every reading. The collimation height is the height of the dumpy level and it is calculated as follows:

Collimation height =100.00 + Back Sight (First collimation height, only changes when instrument position is changed)
Collimation height = Reduced level + Back Sight (second, third, etc collimation height)
Reduced level = Collimation – Intermediate sight.

It is very important when recording to indicate clearly the readings of the change points and new instrument position.

Interview method

Eleven farmers in the upper Kuiseb catchment (in the area of study that is the high and the low rainfall areas) were interviewed and information about farm dams was obtained including quantity obtain maintenance and management of dams. A questionnaire was developed that was used in the interviews (see appendix for questionnaire and summary of interview).

Data Analysis

Data collected from the field were used to plot the contours of the dams and from these plots the depths, areas and volumes were calculated. The depth was calculated by subtracting the lowest recorded point in the dam from the full supply level (100) and the area was obtained by using a planimeter. The volumes was calculated as:

$$\textbf{Volume (m}^3\textbf{) = Area (m}^2\textbf{)* Depth (m)}$$

Another method was used to recalculate the dam basin area using the formula

$$\textbf{Area = C1* Volume^ C2,}$$

Where $C_1$is the slope of the area vs. volume logarithmic function at each contour level, and C_1 is the intercept of these functions. These coefficients have physical meaning but they are mainly used for comparison of dam characteristics. The coefficient C_1 relates to the area and the coefficient C_2 to the shape.

Dams with the same C_2 have the same shape with, at any storage level an area proportional to C_1. Dams with the same C_1 have similar basin areas. The lower the C_2 the steeper the basin and the less the area increases with increasing storage. By implication dams with lower C_2 are deeper (C_2= 0 is a rectangular basin with vertical walls, C_2= 0.67 is a dam with uniform sloping sides in both direction, C_2 approximately 1 is an almost flat dam basin).

The dam's parameters were put into a spreadsheet with the following data from the Department of Water Affairs; monthly demand, average rain fall, gross a- pan evaporation, gross open water evaporation, net open water evaporation, and monthly evaporation depths for analysis. An example of the spreadsheet of one dam is given below:

Table 2. Data from the Department of Water Affairs that are used in the analysis of data from the field

B 8 at 100% capacity

Capacity = 12078 m3 C1= 82.61 C2= 0.53

Month		1	2	3	4	5	6	7	8	9	10	11	12
Monthly demand		1 050	1 050	1 050	1 050	1 050	1 050	1 050	1 050	1 050	1 050	1 050	1 050
Monthly factors (%)		10.3	7.9	7.3	6.6	6.1	5.9	5.4	7.5	9.5	11.3	10.9	11.3.
Gross A-pan Evaporation	3.375	0.348	0.267	0.246	.223	0.206	0.199	0.182	0.253	0.321	0.381	0.368	0.381
Gross Open water evaporation	0.700	0.243	0.187	0.172	0.156	0.144	0.139	0.128	0.177	0.224	0.227	0.258	0.267
Average	0.300	0.070	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03

Rainfall													
Nett water evaporation	2.063	0.173	0.117	0.162	0.126	0.144	0.139	0.128	0.177	0.224	0.257	0.238	0.237

Table 3. Dam parameters required for the establishment of the water flow model.

Year	Month	Initial Storage	Inflow	Storage After inflow	Spill	Storage After spill	Demand	Abstra. volume	Storage After Abstr.	Evapo. Depth	Surface Area	Evapo. Volume	Final Storage
1	4	12078	0	12078	0	12078	1050	1050	11028	0.126	11470	1444	9584
1	5	9584	0	9584	0	9584	1050	1050	8534	0.144	10012	1443	7091
1		6	0	7091	0	7091	1050	1050	6041	0.139	8337	1162	4879
1	7	4879	0	4879	0	4879	1050	1050	3829	0.128	6547	835	2993
1	8	2993	0	2993	0	2993	1050	1050	1943	0.177	4571	810	1134
1	9	1134	0	1134	0	1134	1050	1050	84	0224	862	84	0
1	10	0	0	0	0	0	1050	0	0	0.257	0	0	0
1	11	0	0	0	0	0	1050	0	0	0.238	0	0	0
1	12	0	0	0	0	0	1050	0	0	0.237	0	0	0
1	1	0	0	0	0	0	1050	0	0	0.173	0	0	0
									6300			5778	
								%abstr.	52%		%evap	48%	

For the spreadsheet above it is assumed that just after the rain stops (April) the dam will be full to capacity and there is no further inflow into the dam. The lasting period (performance), the % abstraction and the % evaporation of the dam are calculated within the spreadsheet. The lasting period, which is the performance of the dam, refers to how long water will last in the dam. Percentage abstraction refers to the percentage of the total capacity that can be abstracted for use (demand). Percentage evaporation refers to the percentage of the total capacity that can be lost through evaporation. From the above table (or spreadsheet) dam B8 has a capacity of $12078m^3$, its lasting period is 5 months with abstraction, percentage abstraction is 52% and percentage evaporation is 48%.

Initial storage for the 4^{th} month (April) is equal to the total capacity of the dam. Thereafter the final storage of the previous month will be the initial storage of the next month. The influence of the C_1coefficient on the surface area can be seen when changing the C_1 of the same dam. The surface area and evaporation depth determines the evaporation volume.

Several dry-run analyses were carried out to see how the performance of the dam changes if the following condition were to hold:

- There is no abstraction from the dam at full capacity. This analysis is done by making the column of abstraction volume = 0.

- Dams are 50% full. This analysis demonstrates what would happen if all the dams were smaller.
- Another case was to look at two specific dams and see how long each will last if:
    - 100% demand is abstracted from dam E1 while dam E3 is resting (waiting for dam E1 to be emptied before water can be abstracted from dam E3) and vice-versa.
    - 50% of the demand is abstracted from each dam. This was done to see if using two dams (abstracting water from two dams at the same time) is better than resting dams in terms of water loss through evaporation.

Results

Interviews

Eleven farmers in the Kuiseb basin Area were interviewed on their farm dams and how they manage them.

Table 4. Farmers responses to the questions asked about their farm dams.

Farm dam code	Total # of dams per farm	# of dams with water till December
A	8	6
B	19	3
C	9	2
D	4	0
E	36	22
F	3	3
I	7	0
J	8	1
K	6	0
L	3	0
M	5	0

higher rainfall

Low rainfall

Farms A-F are in the higher rainfall area and farms I-M are in the lower rainfall area. Most of the farms in the higher rainfall area have many dams and 36 out of 79 dams can last until December.

On the management of the farm dams, farmers manage their dams by using bulldozers (some use their own scrappers) to remove sediments at an interval of 7 to 20 years. In one case, silt was removed only after 40 years. According to farmers, the cost of constructing a dam ranges between N$ 20 000 and N$180 000 depending on the size. Farmers feel that maintaining a dam is very expensive and in some cases it can be as higher as excavating a new one. One example was given whereby maintenance cost can be N$35 – 40 000 in comparison to the initial dam cost that was N$180 000. Half of the interviewed farmers in the higher rainfall area would like to have new dams in the future provided there is money. Most of the farmers in the lower rainfall area are

Are any dams

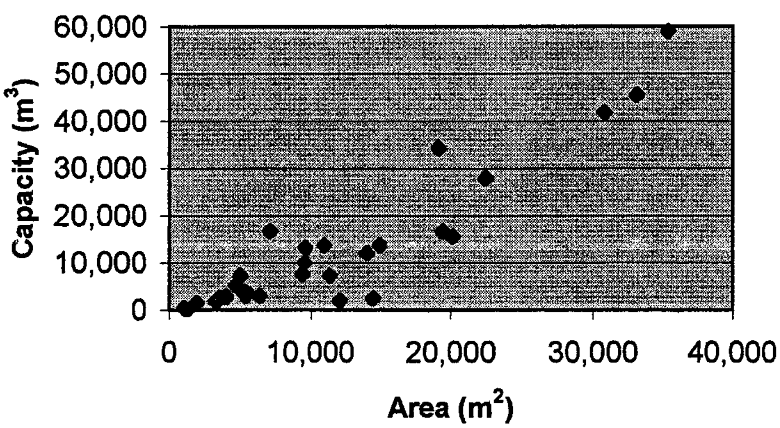
not planning to build new dams. Farmers in the higher rainfall area feel that their dams have no effect on the dams in the lower rainfall (downstream) area. Some of the reasons being that: dams downstream get their water from other directions and that their dams are too small to cause any effect.

Surveyed Dams

A total of 15 students surveyed a total of 29 dams in a period of 14 days in the higher (21 dams) and lower (8 dams) rainfall areas of the Kuiseb catchment. In the higher rainfall area the maximum capacities of the dams range from 59 000 m^3 to 383 m^3, while in the lower rainfall area range from 15 575 m^3 to 94 m^3 (see appendix). For the higher rainfall area only five dams were above 20 000 m^3 (which is the maximum capacity of the dam allowed by the water act of 1956, otherwise a special permit is required).

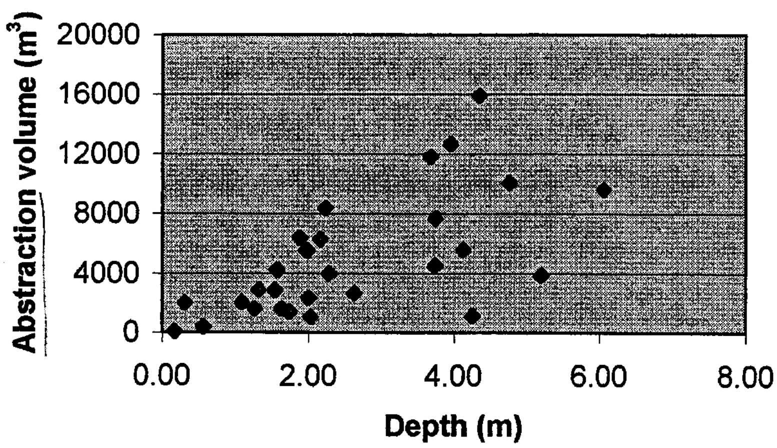
The deepest dam in the higher rainfall area is 6 m and the shallowest dam is 0.31 m, and in the lower rainfall area the range is from 5 m to 0.18 m. When the parameters of all the surveyed dams are combined and treated as a single data set, the median capacity and depth is 7 300 m^3 and 2 m respectively. The relationship between combined dam basin characteristics can be seen from the graphs below.

Fig. 1 Capacity vs. Area of dams surveyed in two sub-catchments of the Upper Kuiseb



Most dams with an area smaller than 20 000m^2 have a volume less than 20 000m^3 (fig. 1) The correlation is 0.92, between surface area and capacity (volume) which is good and will make the extrapolation more reliable.

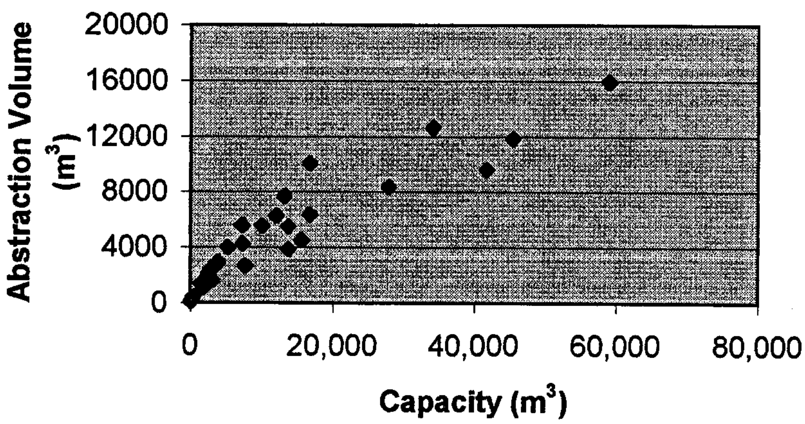
Fig. 2 Abstraction vs depth of the surveyed dams in two sub-catchments of the Upper Kuiseb



abstraction here? What is meant?
- amount able to be abstracted?
- amount abstracted?
- how does it relate to capacity?

In general as the depth of the dam increases the amount of water that can be abstracted does not show a clear pattern. This was shown by the correlation, which is 0.63. Therefore the amount of water that can be abstracted does not necessarily depend on depth of the dam.

Fig. 3 Abstraction vs Capacity of all surveyed dams in the two sub-catchment of the Upper Kuiseb



The shape of fig. 3 indicates that as the capacities of the dams increase, the abstraction volume increases. This is also supported by a correlation of 0.93. Most of the dams have capacities less than 20 000m^3 and from each of these less than 10 000m^3 can be abstracted before the dams dried up.

The largest dam (59 000 m^3) in the higher rainfall area lasts for 14 months with abstraction and 28 months with no abstraction compared to the lower rainfall where the largest dam (15575 m^3) lasts for 13 months with abstraction and 19 months with no abstraction. Below are the results of the abstraction, evaporation and perfomance analysis of the dams in the lower rainfall area (for the higher rainfall area, see appendix). where?

Table 5. The comparison of abstraction, evaporation and performance (lasting period) of dams (at 100% capacity).

Name of dam	Capacity (of dams)	% Abstraction	% Evaporation	Performance (in months)
H 4	15 574. 99	27	73	13
G 7	13 765.73	28	72	11
G 6	7635.34	35	65	8
L 1	3022.18	54	46	4
H 5	2937.75	55	45	4
H 2	1924.17	59	41	3
L 0	1812.00	59	41	3
H 3	93.67	100	0	<1
Average		**52**	**48**	**6**

Table 6. The comparison of dams abstraction, evaporation and performance (lasting period) of dams (at 50% capacity).

Name of dam	Capacity	% Abstraction	% Evaporation	Performance (in months)
H 4	7 877.50	35	65	7
G 7	6 882.87	38	62	7
		50	50	5
		65	35	2
		66	34	2
G 6	3 817.67	84	16	2
L 1	1511.09	84	16	2
H 5	1468.88	100	0	<1
Average		**65**	**35**	**3**

Table 7. The comparison of lasting periods of dams at 100% capacity with abstraction and without abstraction.

Name of Dams	Capacity	Lasting Period (in months)with Abstraction	Lasting Period (in months) with no abstraction
H 4	15 574. 99	13	19
G 7	13 765.73	11	18
G 6	7635.34	8	13
L 1	3022.18	4	7
H 5	2937.75	4	7
H 2	1924.17	3	6
L 0	1812.00	3	6
H 3	93.67	<1	1

From the tables 1-3 above it can be seen that at both 50% and 100% capacities the evaporation volume for bigger dams is higher than abstraction volume. At 50% capacity a higher percentage of the dam capacity can be abstracted and used. Furthermore less water is lost to evaporation. Performance is better when a dam is full (at 100% capacity) than when it is half full (50% capacity). Without abstraction dams do not last much longer.

Water Resource Management

Table 8. Comparisons of lasting periods of dams with 100% abstraction, 0% abstraction and with 50% abstraction

Farm Dam	E1	E3	B1	B 9	A3	A1
Capacity	59 007	45 481	16 734	16741	5239	2836
Surface Area	35 385	33 092	19 460	7 064	4 647	3 961
L.P. 100%	14	11	5	9	3	2
L.P. 50%	18	13	6	13	5	3
L.P. 0%	28	18	7	25	10	9

From the above table it is evident that with no abstraction (i.e. resting a dam), dams do last much longer, however this heavily depends on the surface area and the capacity of the dam. L.P 100% mean lasting period when the full demand is being abstracted only from that dam while other dams are resting. L.P. 0% means a lasting period when a dam is not in use.

Discussion

Methodology

Students were successful in using a method of surveying dams that was introduced to them by the Department of Water Affairs (DWA). The results obtained were sufficient and reliable and the Department of water Affairs (DWA) can carry on using this method.

Interviews

According to the farmers, most of the farm dams were built long ago, and because of siltation and sedimentation of dams, the capacities have decreased. Since it is very expensive to maintain and build new dams nothing much has been done about this in the past 20 years.

Surveyed Dams

Surveys in the two areas of study show shallow dams with fairly moderate volumes. This is against the opinion that existed among the DWA officials that there has been a proliferation of huge dams in the Kuiseb catchment. There are still some (5 out of 29 with capacities greater than 20 000m^3) but not as many as is widely believed. The dams might have been quite deep but due to siltation and sedimentation the capacities might have changed.

Capacities and areas of dams are very important dam basin characteristics that determine the performance of the dam. However the depth also plays a role since the evaporation depth per year is about 2meters in both areas. When building a dam it is very important to take all characteristics (capacity, area, and depth) into consideration.

The correlation between area and volume (0.92) is good for extrapolation using the formula **Area = C1*volume^C2**, because from the aerial photos only the area can be obtained (i.e. a good relationship between area and volume is needed to determine the volume when the area, C1 and C2 coefficients are known).

The amount of water that can be abstracted from the dam depend more heavily on its capacity (Correlation = 0.93) than on the depth (correlation = 0.63).
The dry run analyses starting from 100% and 50% full dams show that a smaller dam is better than larger dam in terms of evaporation. However the performance in terms of meeting supply targets would be worse because the dam is small, so the water gets finished quickly. The shorter the duration of water in the dam the lower the evaporation (because the duration of exposure of water to evaporation is less).

Resting a dam with greater surface area is not efficient, as more water will be lost through evaporation. When 50% demand is abstracted from both two dams (two dams are in use at the same time), the lasting period is prolonged than only one dam is being used, however it is shorter than when there is no abstraction. Though this is the case, by the time the first dam is dry, the water quality of the second dam would have decreased. Dams built for resting purposes should have smaller surface area with depths greater than 2 meters. This is because evaporation depth per year is 2 meters. It is therefore very important to take all the parameters of the dam into consideration for better management of dams in future.

Definitions of terms

Gross A-pan evaporation = monthly factor (rainfall) x Sum of all monthly gross A-pan evaporation
Gross Open water evaporation (for a month) = Gross A-pan evaporation (for a month) x imperical factor
Net open water evaporation (for a month) =Gross Open water – Average rainfall of a month

Initial storage is given (known) as the capacity of the dam
Inflow is given (known)
Storage After Inflow = Initial Storage + Inflow
Spill = Storage After Inflow – Capacity (or initial storage)
Storage After Spill = Storage After Inflow – Spill

Demand is how much water is needed from a dam per month
Abstraction is the amount of water that can be obtained from the dam per month (demand)

Storage After Abstraction = Storage After Spill – Abstraction
Evaporation Depth = Net Open Water Evaporation for a month (Gross open water evaporation – average rainfall
Surface Area = Slope (C1) x Storage After Abstraction ^ Intercept (C2)
Evaporation Volume = Surface Area X Evaporation Depth
Initial Storage = Storage After Abstraction – Evaporation Volume
%Abstraction = the proportion of the dam capacity that can be obtained before the dam dries up
% Evaporation = the proportion of the dam capacity that is evaporating from the dam until the dam dries up
Performance = refers to the lasting period of water in the dam

Chapter 2: Water and Land Use

By: Muduva, Theodor, Nashipili, Ndinomwaameni and Shigwedha, Laina

The Kuiseb catchment stretched about 30km west of Windhoek and runs westwards to the Atlantic Ocean at Walvis Bay. The catchment occupies an area of 14700 kilometers in squares. Along the catchment farms occupy the area. Both commercial and communal farmers depend directly in the land, (Dausab at al 1994: iv by Jacobus et al). The water and land use team looked at rangeland conditions during a two months survey of the Kuiseb Catchment.

Vegetation and soil

Soil type varies in the sub-catchments. The low rainfall area has a higher proportion of soil particles smaller than <63, the fraction that is most commonly found in dams. But soil fraction in dams could not be compare between the two sub-catchments, as no soil samples were taken from dams in the high rainfall area. High rainfall area is more stable in terms of ground cover, soil erosion resistance and nutrient availability. The water run-off in the high rainfall area is relatively low due to a higher number of obstructions.

The high rainfall area has higher grass and bush species richness than the low rainfall area. The frequency occurrence of both perennial and desirable species is significantly different between high and low rainfall areas. This can be attributed to the rainfall variance between the two sub-catchments. The high rainfall area has a high mean annual rainfall of 248mm and 121mm respectively. In both sub-catchments trees taller than two meters were scarce but more bushes shorter than 50cm were common.

This can be due to trampling and browsing by livestock and game. This was observed during vegetation assessment in the field. The palatable Boscia species (*Boscia albitrunca* and *Boscia foetida*) have been hammered everywhere by stocks and appear to contribute little to overall browse for livestock and game. In the low rainfall area there were substantial differences between farms in the extent to which the *Boscia foetida* is browsed and damaged (larger branches broken) but we did not document these differences quantitatively because of time and access limitations. Bush encroachment was not advanced either area but bush encroaching species are present (*Acacia mellifera* in the high rainfall area and *Acacia reficiens* and *Dichrostachys ceneria* in the low rainfall area). Bush encroaching species are more likely to occur near dams. *Acacia reficiens* and *Acacia mellifera* are short bushes or trees found throughout the 1200m transect in high and low rainfall area respectively.

Dams and boreholes.

Eleven farmers were selected for interviews from where data was gathered. All farming activities on farms are rainfall dependent. Farmers respond to rainfall or lack of it by managing stock numbers and by depending personally upon boreholes and dams. Dams and boreholes are important sources of water and all farmers interviewed have these on their farms.

On the 11 farms there were 126 boreholes. The number of boreholes per farm ranged from one to 48 (mean = 11). Seven of the 11 reported that they use borehole water for both domestic and livestock. Five use water to provide for game in addition to other uses. Two farmers reported using water for irrigation. One used water for a swimming pool. Two farmers reported removing silt from boreholes. One reported fencing off a livestock water trough. Some boreholes fail during the dry season and are used sparingly for livestock. Boreholes in the lower rainfall area are particularly prone to failure. On one farm only 8 of 48 boreholes are in use. Five dried up and 35 were either dug in the wrong places or have repair problems. Other boreholes provide water throughout the year.

Twenty-nine dams were surveyed, the biggest dam holds 59,007.00 cubic meters of water is in the higher rainfall area. The small dam holds 93.34 cubic meters is found in the lower rainfall area. The range in differences is due to the rainfall figures in the two sub catchments. The mean rainfall in the higher rainfall area is 248 mm/annum and in the lower rainfall area is 121 mm/annum. The number of dams ranged from 2 to 36 (Mean = 9). The number of dams on the lower rainfall farms was 25 (mean = 5) and on the higher rainfall area 77 (mean = 13). Most farmers use dams to recharge boreholes.

Farmers respond to rainfall or lack of it by managing stock numbers and by depending personally upon boreholes. Seven of the 11 farmers reported removing silt from dams. Two farmers reported the need to repair broken pipes associated with dams. One reported using dams only for livestock.

Seven of 11 farmers reported using their dams for livestock, game and ground water recharge. Two reported using their farm dams for irrigation and domestic use. One farmer did not report the use made of dams.

Borehole water is a necessity for farm operation. All farmers depend upon borehole water for domestic use and most use boreholes to manage stock during part of the year. None of the farmers reported high availability of groundwater and boreholes appear to be used primarily for domestic use and to carry livestock through dry season(s).

Land use and management

The higher rainfall area has more dry matter (productive) per hectare compared to the lower and this explains why these farms have a higher carrying capacity compared to the lower rainfall area. This is also why farms in the lower rainfall area are larger as they need more fodder to support the same number of animals. Seven farms reduce stock during droughts, which can be a particularly serious problem in the low rainfall areas. The land use pattern in both farms is almost the same and consists of livestock, game, hunting and tourism. Allowing animals to roam freely as management practice is done in two farms in the high rainfall area and in two farms in the low rainfall area.

Conclusion

The rangeland condition in the high rainfall area is good compared to the low rainfall area, but this influences the run-off in the upper catchment. Farmers downstream can hardly practice some grazing practice due to low rainfall. Farmers in both sub-catchments under stocked their farms.

Recommendation

Farmers should practice vegetation and rangeland assessment in their farms. Long and short-term management techniques such as rotational grazing and reduction of stock during severe drought should be taken into consideration.

Though bush encroachment seems not to be a problem in the two studied catchments a combination farming of both grazers and browsers can help keep bush encroaching under control.

Chapter 3: THE WATER BALANCE MODEL

By: *Iiputa Gerhard, Nakale Tufikifa and Nantanga Komeine*

Introduction

The water balance model is a mathematical means of relating the water going into and coming out of a catchment under different conditions. It also explains the effect of dams on the virgin or natural catchment flow. Natural catchment flow refers to what the flow would be if there were no dams or any other development.
In theoretical approach, the model involves working from the natural catchment flow, to investigate the effect of development. Due to existing river flow information for the developed catchment (with dams), it is relatively easy to use an inverse approach, working backwards from the reduced (measured) flow (with dams) where runoff data is available to determine the natural flow.

This would simply mean,

Natural flow = inverse reduction factor multiplied by reduced flow

The inverse reduction factor is a coefficient, obtained by trial and error calibration of the model that converts the reduced flow to the natural flow.

The main parameters necessary for development of the water balance model are initial storage, inflow, reduced (measured) catchment flow, calculated catchment flow, spill from upstream, spill (overflow) at dams, demands, abstraction, evaporation and final storage. All of these parameters are volumes in cubic meter (m^3), and are arranged sequentially in the form of a spreadsheet.

* How do these spreadsheets relate to this?

Methodology

A water balance model was developed in the form of a spreadsheet for a higher and a lower rainfall sub-catchment. Five dams, A3 and A4, B4 and B6 and F1 were surveyed in the higher rainfall sub-catchment. However, dam G1 was not surveyed, but it has similar characteristics to dam F1, which was surveyed but is outside the higher rainfall sub-catchment. The dams surveyed in the lower rainfall sub-catchment were G7, G6, H5, H4, H3, H2, L1 and L0. *

The data used to formulate the model were obtained from the following sources:

1. From Department of Water Affairs (DWA):
   - Monthly rainfall data
   - Runoff (inflow)data
   - Evaporation data : which were taken from the DWA Evaporation map for Namibia, Report No: 11/1/8/1/H1, Hydrology division, October 1998
2. From dam group (SDP 9):
   - Dam full supply volume(capacity) pg 10
   - Dam coefficients C_1 and C_2

3. Monthly demands were calculated as follows:
From the interviews it was found that farmers in the higher rainfall sub-catchment have approximately 634 heads of large livestock. Each head of livestock is believed to drink around 50L/day. Hence:

634 heads of livestock
X 50L/day
31700 L/ day
Per month, the demand in liters is:
31700 L/day x 30 days/month = 951 000 L/month

Per month, the demand in cubic meters is:
951 000 L/month x 10^{-3} m^3/L = 951 m^3/month
Other demands were estimated to be around 100 m^3/month. These other demands include volumes use by some small wild game.

Total monthly demands: 951 m^3/month + 100 m^3/month ~ 1050 m^3/month
The same calculations were done for the lower rainfall sub-catchment with 170 head of large livestock. The total monthly demand for the lower rainfall sub-catchment is 325 m^3/month.

4. Other calculations in the spreadsheet
- **Initial storage** = Final storage from previous month for a particular dam
- **Storage after inflow** = Initial storage + Inflow,
- **Spill** = Storage after inflow – Dam capacity, otherwise = 0 when storage after inflow < capacity. It is the overflow of the dam.
- **Storage after spill** = Storage after inflow – spill
- **Abstraction** = demand if storage after spill > demand, otherwise abstraction = storage after spill.
- **Storage after abstraction** = Storage after spill – abstraction
- **Surface area** = C_1 X Volume^{C2}
- **Evaporation volume** = surface area X evaporation depth (from DWA manual)
- **Final storage** = Storage after abstraction – Evaporation volume
- ? **Calculated catchment flow** = Inverse reduction factor x Measured sub-catchment flow x the sub-catchment factor
- **Inverse reduction factor** = the factor which reverses the reduced sub-catchment flow to the natural flow. It is the ratio of the reduced sub-catchment flow to the natural catchment flow.
- **Catchment factor** = the area of the dam catchment divided by the area of the sub-catchment.

Table 1: The parameters in the spreadsheet model and how they were obtained

Model components	**How obtained**
Initial storage	Calculated
Measured catchment flow	Measured (from DWA)
Calculated catchment flow	Calculated
Upstream spill	Measured, Calculated
Inflow	Calculated
Storage after spill	Measured, Calculated
Demand	Assumed
Abstraction	Assumed
Storage after abstraction	Measured, Calculated
Evaporation depth	Measured, Calculated, Assumed
Surface area	Measured
Evaporation volume	Calculated
Final storage	Calculated
Yearly Statistics	Calculated

I haven't found these data.

5. Yearly Statistics

The annual mean inflow, annual mean spill, annual mean demand, annual mean abstraction, and annual mean evaporation volumes for each dam were calculated for each hydrological year which starts in October and ends in September of the following year. These annual parameters were calculated for the period of 1978 to 1994.

Results

The water flow model estimates that the higher rainfall and lower rainfall sub-catchments are holding back 77% and 15% of the natural flow respectively during median rainfall years (see Table 2). For some of the model components, the assumptions lead to unrealistic figures (see Table 3 & 4). The tables below shows the main findings from the water balance model for the two sub-catchments where the survey was carried out. The discrepancies due to the assumptions of the model are shown in the zero values for evaporation and spill over a period of 16 and 17 years in each sub-catchment, unrealistic figures.

Where are all the figures that went into these calculations?

Table 2: This table shows the reducing effect of the dams on the virgin runoff in the two sub-catchments surveyed during the 16 and 17 years period of the lower rainfall and high rainfall sub-catchments respectively.

	Higher rainfall sub-catchment	Lower rainfall sub-catchment
	Runoff (m^3)	**Runoff (m^3)**
With dams	6,746	105,970
Without dams	29,321	124,250
Difference	22,575	18,280
Reduction	77%	15%

— how was runoff calculated?

As table 2 shows, the runoff for the two sub-catchments varies. The high rainfall sub-catchment has a higher reduction of flow, but a smaller runoff in general when compared to the lower rainfall sub-catchment. why? — poor soil

Table 3: Statistical medians of the yearly inflows, spills, abstractions and evaporation volumes (m^3) for each dam in the higher rainfall sub-catchment over a period of 16 years from 1978-1994.

Dam	A4	A3	B4	B6	G1
Inflow (m^3)	792	88	3,786	4,931	14,777
Spill (m^3)	0	0	0	1,701	0
Abstraction (m^3)	792	88	3,190	1,050	1,050
Evaporation (m^3)	0	0	1,348	0	3,483

← how were these calculated? no flow.

Table 4: This shows the statistical medians of the yearly inflows, spills, abstractions and evaporation volumes (m^3) for each dam in the lower rainfall sub-catchment over a period of 17 years as from 1978-1995.

?

Dam	H 5	H 4	G 6	G 7	H 3	H 2	L 1	L 0
Inflow (m^3)	2,692	3,490	1,141	3,440	1,994	55,522	1,396	67,145
Spill (m^3)	0	0	0	0	1,713	52,636	0	64,204
Abstraction (m^3)	1,026	1,484	748	353	110	1,848	967	1,421
Evaporation (m^3)	1,457	1,975	357	433	0	479	480	527

Discussion

This water balance model represents a first approximation in Namibia of inputs and outputs of water flow in an ephemeral river catchment as influenced by dams. With this model we were able to obtain a quantitative estimate of the influence of dams on the flow in the upper Kuiseb. There is a large range in the reduction of the natural flow between the two studied sub-catchments (see Table 2). Interestingly enough, the lower rainfall sub-catchment has a higher runoff per unit area

* How do the farm dam nos relate to farm names? - e.g. see runoff calcs.

Friedman 6,723,000 m³

than the higher rainfall catchment. This difference can be accounted for by the fact that the lower rainfall sub-catchment is more mountainous and has a larger surface area than the higher rainfall sub-catchment. Therefore, there is less infiltration and more runoff in the lower rainfall area. The lower rainfall sub-catchment has smaller dams than the higher rainfall sub-catchment (Average dam capacity, 5852 m^3, 12811 m^3 respectively) which could possibly be due to greater sedimentation (see land and water use chapter). It is also possible that this difference can be accounted for by the smaller surface area of dams in the lower rainfall catchment (average dam surface area, 9120 m^2, 13270 m^2 respectively).

Even though the dams in the higher rainfall sub-catchment intercept a majority of local flow on average and moderately high rainfall seasons, their effect on river flow during high rainfall seasons is limited. Since the lower Kuiseb is dependent on these high rainfall seasons (Jacobson *et al*, 1995) for recharge, farm dams' impacts on the amount of water reaching the lower Kuiseb in most but not all years is limited. Thus, for example, the recharging floods of 1996 and 2000 that recharged the lower Kuiseb aquifer with several million cubic meters of subsurface water could only have been diminished by 64052 m^3 of water if all dams were empty at the start of the event. However the dams were not in fact empty at that time. However effects of farm dams may be significant on local level (Most of our interviews with the farmers yielded the response that their dams have no effect on downstream users and that they are not affected by upstream users). The model can be used to further investigate this issue and emphasize the need for water resource management on a basin scale. When integrated with information concerning land and water management these results can serve to inform water managers and decision-makers in the entire Kuiseb River catchment.

In order to decrease, while we calibrate the model, the distortion of flow data due to the few high years of rainfall, it is more relevant to work on frequency statistics, particularly, on medians. Medians reflect conditions that are neither too high nor too low even though the variability is a key characteristic of this arid area. Hence the model was calibrated using medians, thereby describing a "typical" year in the Kuiseb that is not an overestimation or an underestimation of the water flow. This avoids use of statistical means for the measured and calculated flow data that would overestimate the amount of water flowing through the catchment due to the out-laying effect of high rainfall years.

Another important calculation in the spreadsheet is the reduction ratio. This value represents the percentage of natural flow held back by dams and is the ratio between the measured value for flow with dams and the calculated value of flow without dams. To aid in calibration of the model, the ratio between the natural flow and the capacity of dams was also determined.

Limitations of the model

Even though the model has given relevant results there are some limitations to its simplistic design. There is not enough data available from historical records to fully validate the model. Some years did not have complete runoff and rainfall data. These gaps led to our estimation of monthly average rainfall values that are assumed to be the same for all the years.

In addition, there were several other assumption made throughout the calibration of the spreadsheet. First, all areas within both sub-catchments were assumed to contribute in a uniform manner to surface runoff. In reality, some areas within a sub-catchment may be contributing differently to the sub-catchment runoff. Second, loss of water through infiltration and evapo-transpiration has not been accounted for in the model. River losses may on average be correct for the two test sub-catchments. All demands were estimated to be 1050 m^3 for the higher rainfall sub-catchment and 325 m^3 for the lower rainfall sub-catchment. Even though these were estimated by using current stock values, these demands may change from year to year or month to month.

If the storage of the dam is more than the demand for that month, evaporation volumes from the dam surfaces are estimated as if evaporation had occurred in one extraction. However, realistically, evaporation occurs continuously throughout the month. This assumption leads to an error in estimation if the storage in the dam is less than the demand. For this situation, the model claims no evaporation occurred for that particular month (see Table 3 & 3). In reality however, it is very unrealistic that there is no evaporation over a month (as long as the dam contains water).

Finally, the model assumes that a spill upstream reaches the next dam downstream without any losses. In reality all of a spill will not reach any downstream dams due to infiltration, evapo-transpiration, or any unrecorded extractions.

In conclusion, the water flow model should be used in the future by DWA for further studies of the Kuiseb and other ephemeral river catchments. To improve the model, rainfall, infiltration, and evapo-transpiration must be included. In addition, to further refine the model we suggest involving the farmers of the sub-catchments in a participatory manner in monitoring their dams spill, evaporation, and measuring the level of the water table level.

* maps of surveyed + rem. study
sensed dams don't overlap.

Chapter 4: GEOGRAPHICAL INFORMATION SYSTEMS AND REMOTE SENSING

By: *Katshuna Micheal, Matros Anna and Muvi-Tjikalapo Muatala*

Objective

The objective of this analysis is to determine if it is possible to use satellite remote sensing to locate dams and calculate their sizes, and to determine the vegetation cover in the upper Kuiseb catchment.

Introduction

The rational to survey dams and vegetation by using high-resolution satellite imagery (Landsat TM) is based on the unique spectral characteristics of water and vegetation recorded by the satellite. Water, for instance has a high absorption of light in the near-infrared (band 4), middle-infrared (band 5) and the thermal band (band 7), and vegetation has a low reflectance of red light (band 3) and high reflectance in the near-infrared spectrum. These characteristics suggest that it is possible identify water and abundance of vegetation by using Landsat TM imagery.

Water can be identified by using various combinations of the near-infrared, middle-infrared and thermal bands. For instance, a simple standard method based on the fact that water has a high absorption of light in the thermal band is to display pixels with low values in the thermal band, giving an approximation of occurrence of surface water. A draw back of this method is that shaded areas also tend to have a low reflectance in the thermal band and therefore also will be "classified" as water.

In the literature at hand the mapping of small water bodies like farm dams has not been given the same attention as mapping of vegetation. Therefore, the team members have mainly developed the methodology used for this study, with limited reference to previous studies.

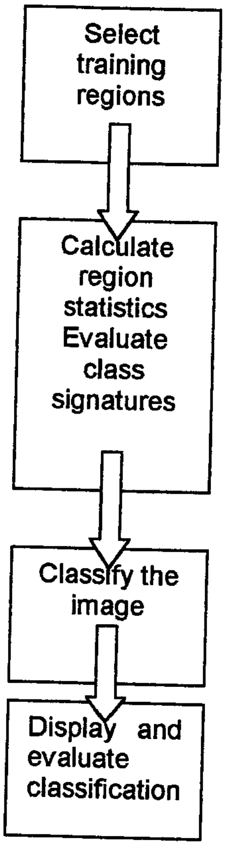
The main task in our project is to map out farm dams and vegetation composition cover by using Landsat Thematic Mapper (TM) imagery in the upper Kuiseb catchment using Geographical Information System and Remote sensing tools.

Geographical Information Systems (GIS) are based on digital maps (maps that can be altered in the computer). Remote sensing looks at features on the ground (land surface) via satellite images or aerial photos. Satellite images are known as raster images and are in the form of grids or matrices of points or pixels. These points are arranged like rectangular cells in rows and columns each having a numerical value relating to the reflected light transmitted from the area on the ground covered by the pixel.

Satellite images have one or more bands or channels of information. These bands represent different wavelengths of detectable radiation in the electromagnetic spectrum. The images are usually displayed by using an arbitrary colour scheme to indicate different data values; for example, Landsat TM has seven bands ranging from Visible blue to far Infrared. Normally 3 bands are viewed at a time by using Red, Green, and Blue colours, generating a true colour picture.

Methodology

The diagram below outlines the steps followed for analysis of the satellite images:



The selection of training regions was based on our information from the field.

Calculate statistics for pixels in each training region (minimum, maximum , mean values, standard deviation, scattergrams and histograms).

Develop a classification algorithm that classifies farm dams and vegetation type and density.

Display the output-classified image, assign colours to classes, and overlay classes.

Satellite images

Two satellite images were used; the Landsat 7 ETM 7, scene 178 076 which were acquired on the 17th of May 2000 and the dry season image of the 19th of August 1999. The scene was then formatted for ER-Mapper. The projection used was WGS 84. ER-Mapper software was used for the analysis. The National Remote Sensing Centre in Windhoek did geographic correction of the images.

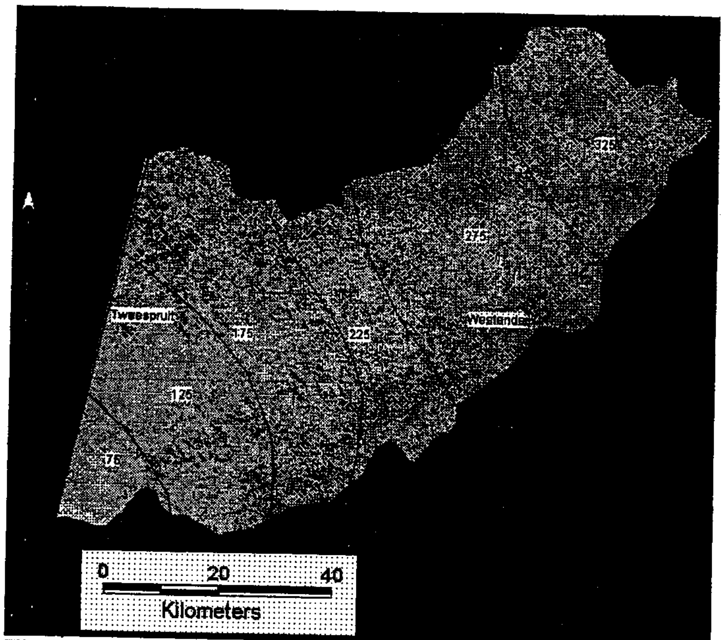


Figure 1. The image shows the upper parts of the Kuiseb catchment covered by scene 178-076. The image was received the 17th of May 2000. The isohyets on the map show the mean annual rainfall in the area. The two sub-catchment that were investigated during the fieldwork, Westende and Tweespruit are also outlined.

Defining training areas.

The location of each training area was recorded during the field survey. The GPS (Global Positioning System) co-ordinates of the surveyed vegetation transects and dams were plotted on the whole Kuiseb catchment map using Map Info (GIS). The study areas are presented in figure 1 below.

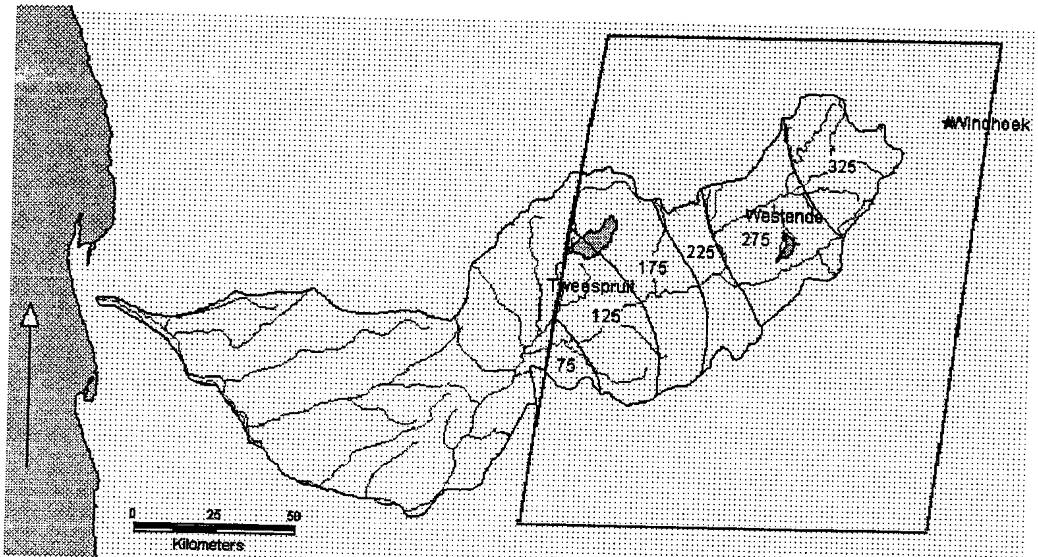


Figure 1. This map shows the extent of the study area. The red rectangle outlines the area covered by the remote sensing analysis. This area coincides with the Schlesien sub-catchment. The two sub-catchments Westende and Tweespruit where the fieldwork was carried out are outlined in orange. The isohyets show the annual mean rainfall in the area.

The plotted points were exported to ER-Mapper. The sub-catchments where the fieldwork was done were identified on the topographical map. Four referral points were identified on the map and the scanned sub-catchments were digitised. The digitised sub-catchment was then exported to ER-Mapper. This was done to calculate the area and the number of dams within sub-catchments and to determine the percentage of land occupied by dams in each sub- catchment.

Training areas were defined using the GPS point recorder in the field . Training regions for water or vegetation are defined by drawing polygons in areas with typical spectral characteristics for each class. Supervised classification will then search for all other pixels with similar spectral characteristics. The resulting image has a band whose numerical value at each point is the assigned class value. The classes will have the same names as the training regions. Dams and four vegetation classes were defined as training regions. For each class at least 4 training regions were defined.

Statistics

Statistics showing the spectral characteristics of each class were calculated and analysed. Histograms were then used to view the training regions using one band. Scattergrams were used to compare the spectral characteristics of different classes in two bands at a time. See Figures 2 and 3, which show the difference between scatter and histogram. :

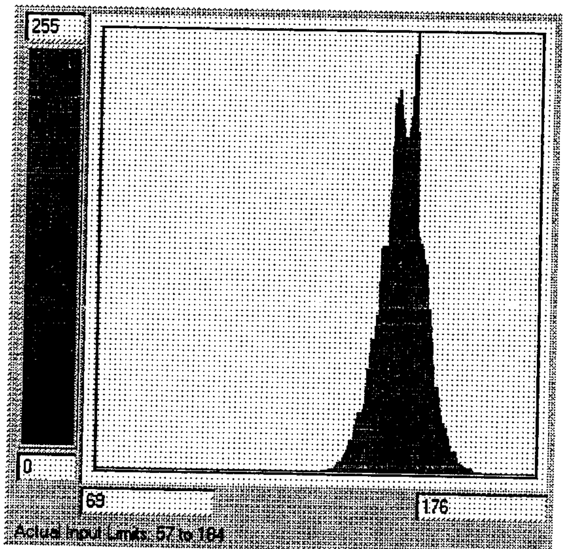


Figure 2. The histogram is used to display the spectral distribution of the pixels in the scene. The values for any pixel in a satellite image range from 0 to 255. By comparing the histogram for one or many classes, e.g. dams versus vegetation in all bands, valuable information about the different classes spectral characteristics can be obtained. This information is then used to determine the classification algorithm to be used for the final classification of the satellite image.

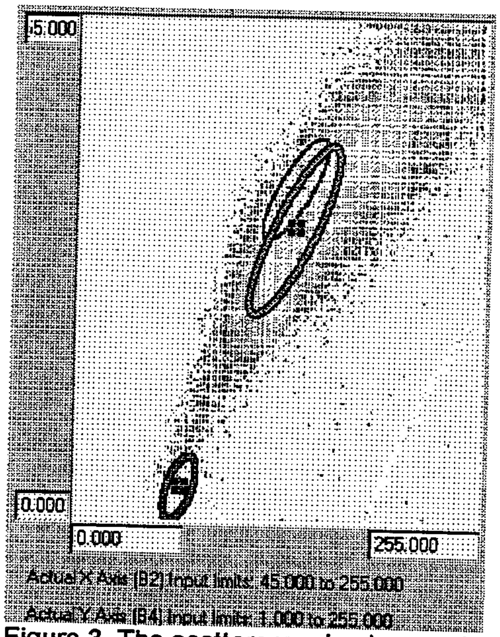


Figure 3. The scattergram is also used to compare the spectral characteristics of different classes in two bands at a time. In this figure band 2 (green light) and band 4 (near infrared) is plotted. The central points of the three circles illustrate the mean and the circle boundaries illustrate the 95% probabilities for a pixel to belong to the class. In this scattergram three classes are plotted, the lower circle is Dams, the two above are two different vegetation classes. From the scattergram it is clear that by using band 2 and 4 it would be possible to separate dams from green vegetation but that it might be difficult to separate the two different vegetation classes.

Classification

The classification of the satellite images was done by using Supervised classification. A number of different Supervised classification types and parameters were tested for the classification. Both Maximum Likelihood and Minimum Distance classification methods were used together with simple formulas. Several combinations of parameters were tested in order to get as accurate a classification as possible. Various threshold values or formulae were tested to help remove confusing features such as mountain shadows and cloud shadows on the image to make it easier to locate the features under analysis.

The farm dams that were surveyed were located, areas and volumes were calculated and then that data was used to extrapolate the areas of the dams in the entire upper Kuiseb catchment. The relationship between area and volume was also determined. The total percentage that farm dams occupy on the land was also calculated.

The SDP Water Index (WI)

To improve the classification of water a "water index" was developed. The index was calculated by dividing Band 2 with band 5 (B2/B5). The ratio is based on the fact that water has a high reflectance in the green spectrum and a low reflectance in the middle infrared spectrum. By creating this ratio water and shadows are highlighted in the satellite image see figure 4 below.

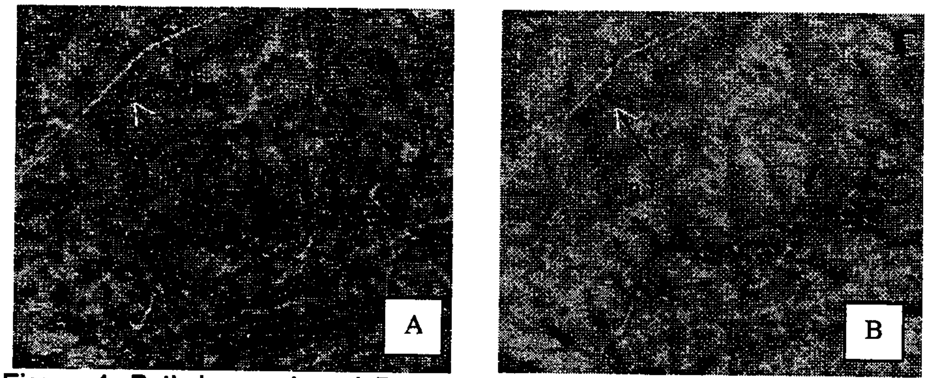


Figure 4. Both image A and B are displayed with Blue=band 1, Green=band 2. Image A is highlighting dams and shadows by displaying the band ratio b2/b5 as red, while image B is highlighting the green vegetation by using the NDVI as red. For image A the red areas are either dams or shadows while the red in image B is green vegetation. The redness of the NDVI indicates the amount of green biomass, the redder the more green vegetation there is. Note the difference in reflectance for dams in image A and B.

Normalized Difference Vegetation Index (NDVI)

NDVI was used provide accurate estimates of biomass, since it has been widely correlated with green biomass and its sensitivity to soil background and to atmosphere,
except at low plant cover. It's used to take a quick qualitative look at the vegetation cover in an image. See figure x+3 (B) showing the spectral signature of green vegetation. The NDVI is calculated by the following formula (B4-B3)/(B4+B3). B4 is the Near infrared band and B3 is the red band. The result of this ratio has pixel values in the range of –1 and 1. To make it possible to use the ratio in a classification the values has to be stretched to values between 0-255. This was done by applying a look-up table.
For further information about NDVI and its use for vegetation mapping, see Appendix 1.

Calculation of volumes of classified dams

The volume of the classified dams were calculated by using the following formula V=(A/C1)^(1/C2), where A is the area of the calculated dam, Cl=45.1 and C2=0.57.
C1 and C2 were defined based on the relationships between the area and volume of the surveyed dams. Each surveyed dam had a specific C1 and C2. The constants used for calculating the volume of the classified dams were averages of the C1's and C2's of the surveyed dams.

Results

Table 1: Shows a summary of the number of dams and their surface areas in different rain zones. The density of the dams shows the number of km2 per dam.

Rain zone (mm)	Rain zone area	Number of dams	Density of dams	Min size (m2)	Max size (m2)	Average size (m2)	Total dam area (km2)	Km2/dam	Dam area/total area (%)
325	964.512	67	0.0695	10387	551974	36924	2.47	14.4	0.256
275	143.002	56	0.3916	2566	10378	5699	0.32	25.8	0.022
225	670.043	8	0.0119	1593	2565	2440	0.02	180.4	0.001
175	137.964	28	0.2030	1586	1592	1589	0.04	34.4	0.005
125	1034.741	28	0.0271	1581	1586	1583	0.04	34.4	0.005
75	197.565	6	0.0304	1577	1581	1579	0.01	160.8	0.001
TOTAL	**3148**	**193**		**3215**	**94946**	**8302**	**2.91**	**75.0**	**0.048**

Table 2: Illustrates the surveyed area and volume in relation to the classified area and volume. C1 and C2 are constants used to calculate the relationship between area and volume, taking the shape of the dam in consideration. The yellow coloured cells indicate the overestimation of the classified areas, while the red shows that the areas has been severely underestimated than the rest.

Dam	Surveyed Area	Classified(Y/N)	Classified Area Maxlikelyhood (1)	Shape C1	C2	depths	Classified Volume	Surveyed Volume
B1	19460.00	Y	26960.00	171.63	0.48	1.88	37606.58763	16734.35
B8	14083.20	Y	609.70	82.61	0.53	2.16	43.4403718	12077.89
A2	9592.00	Y	609.80	10.74	0.72	3.75	273.1275257	13206.90
A4	4959.90	Y	1585.00	37.41	0.52	4.13	1345.631279	7227.26
E1	35385.00	Y	58210.00	11.15	0.74	4.35	105669.4964	59006.88
E2	9560	Y	9022	62.96	0.56	1.97	7086.392196	10066.91
E3	33092.50	Y	29900.00	21.71	0.69	3.69	35423.52968	45481.30
E4	22468.50	Y	13300.00	115.25	0.53	2.23	7779.713396	27886.50
	148601.10		**140196.50**	**513.46**	**4.77**	**24.16**	**195227.92**	**191687.99**

8) 191,688
23,961

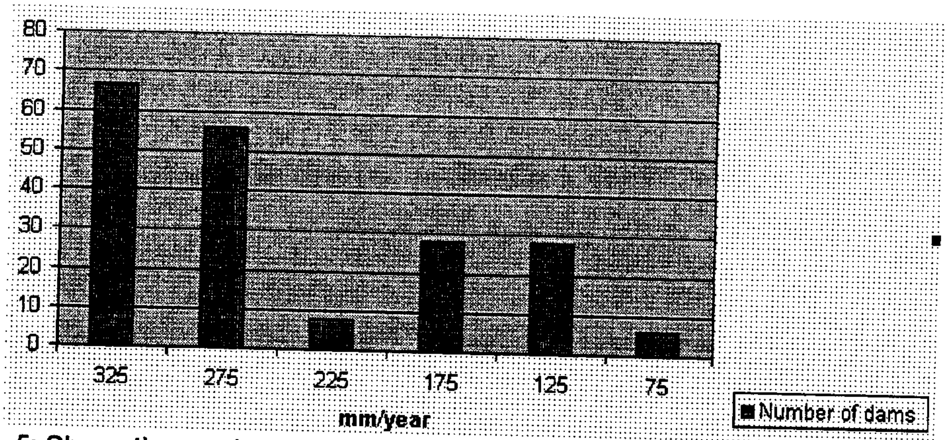


Fig. 5: Shows the number of classified dams in different isohyets in the upper Kuiseb catchment.

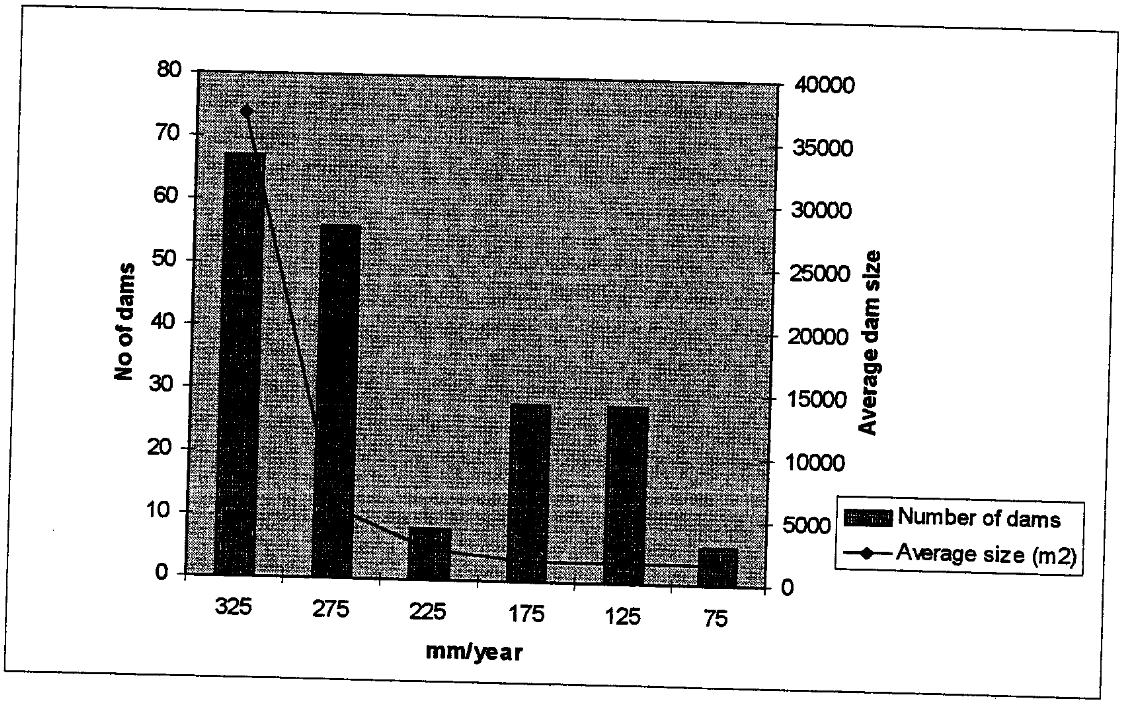


Fig.6: Shows the average size and the number of dams in the different rainfall isohyets in the Upper Kuiseb.

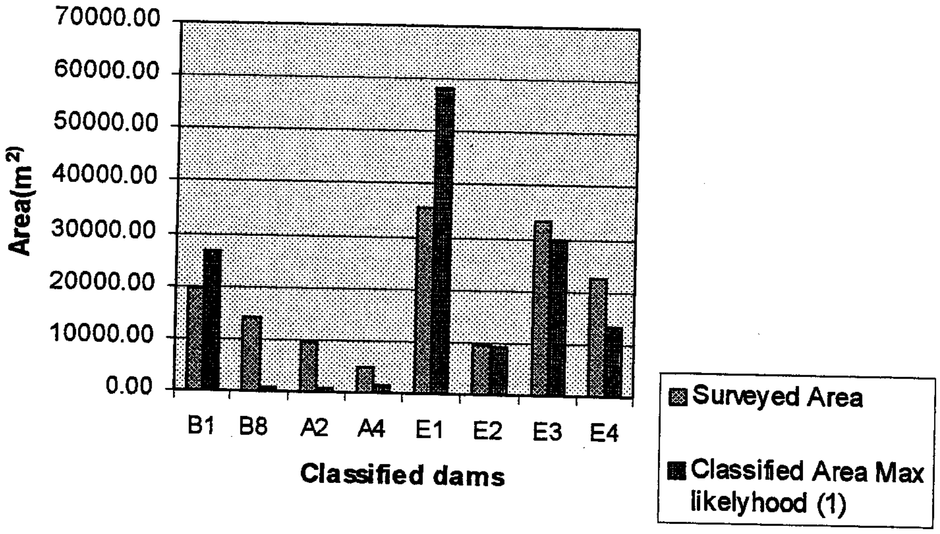


Figure 7: Shows the surveyed area and the classified area for the classified dams in the upper Kuiseb catchment.

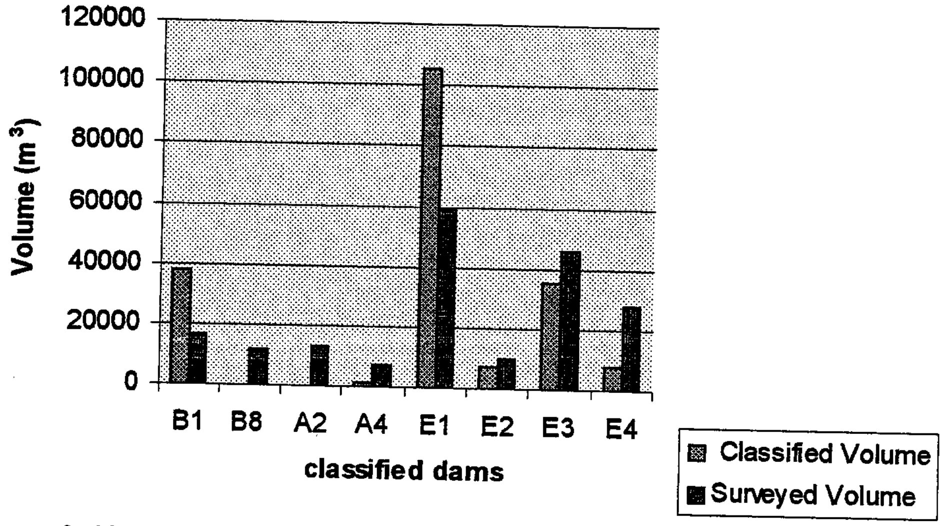


Figure 8: Shows the classified and surveyed volume of the classified dams.

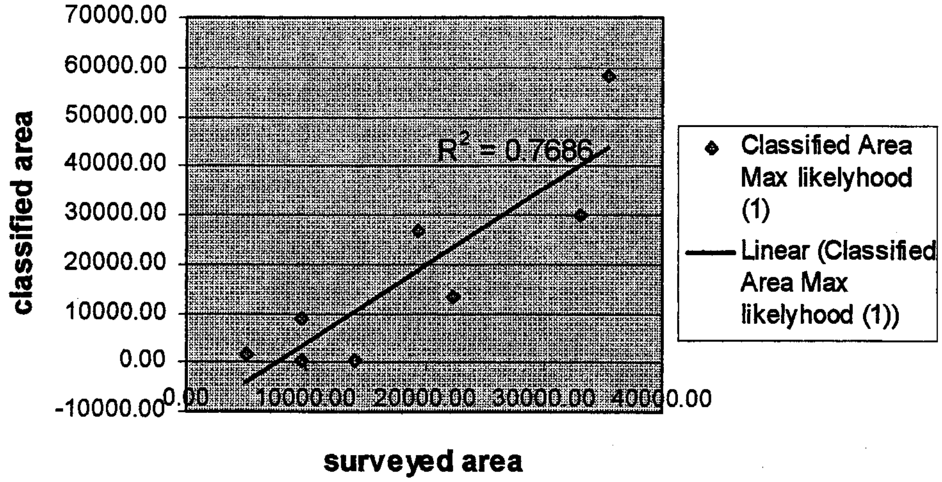


Figure 9: Shows the relationship between the classified area and the surveyed area.

Comparison of vegetation density in the two sub-catchments

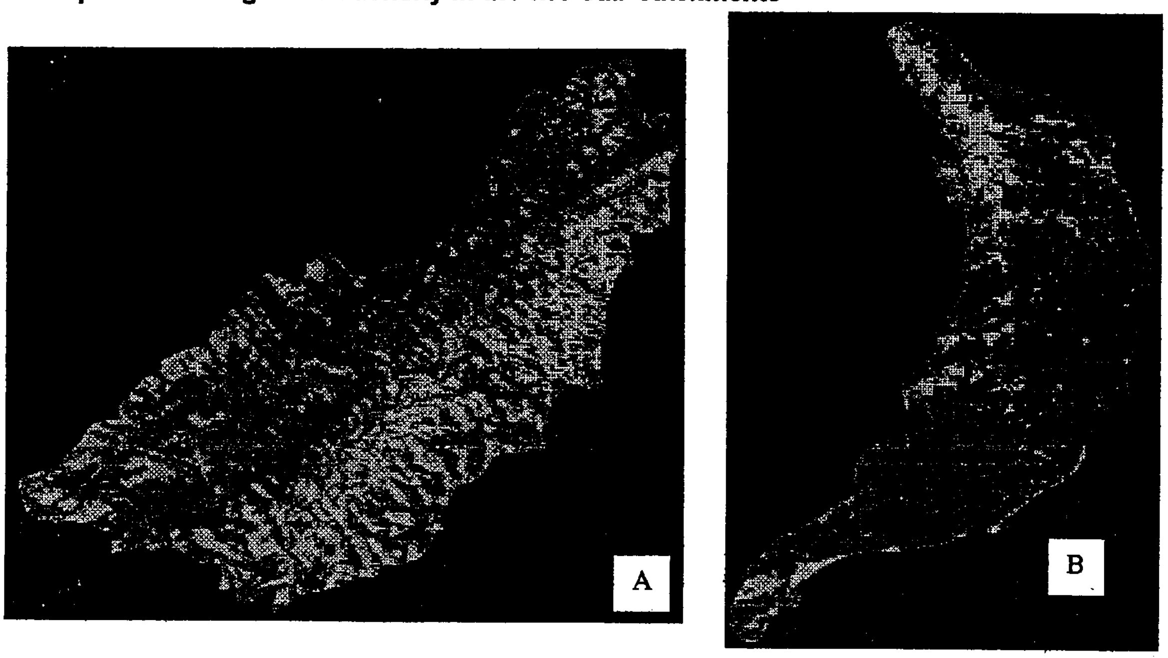


Figure 10. The two maps show the vegetation density in the two sub-catchments. Map A shows the sub-catchment in the lower rainfall area and map B shows the sub-catchment in the higher rainfall area. The dark green colour indicates dense vegetation and the light green colour indicates less vegetation. Grey is bare ground and blue is dams or shadows. The large number of blue pixels in the drier sub-catchment is mainly shadows due to the more rocky terrain.

Discussions

After locating 15 of the 29 dams surveyed in the satellite image only 8 dams were classified by the Maximum likelihood using band 2, 5, 7, NDVI and H2O. Of the eight classified dams, the areas of 6 dams were underestimated in the classification. 4 of these underestimated dams are dams with the surveyed area of less than 15 000 m2. The remaining 4 classified dams have a surveyed area of more than 15 000 m2, and out of these 4, 2 have been overestimated and the other two have been underestimated. Looking at the above descriptive results plus table 2 and figure 7, one can conclude that the surveyed area of the dam might have a significant influence on how the dam is classified in the satellite imagery. For instance in this case the smaller the area of the dam the higher the possibility of it to be underestimated or not to be classified at all. The reason for this is because the pixel size has a minimum resolution of 30 x 30 m.

Using the same classification (Maximum likelihood using band 2, 5, 7, NDVI and H2O) as above, 193 dams were classified in the Upper Kuiseb catchment. This can be an under estimate, because the dams smaller than 600m2 were filtered out. This was done to differentiate clearly between dams and shadows. Looking at figure 5 above one can say that in the higher rainfall area there are more classified dams compared to the lower rainfall area. This might be that the low rainfall areas have smaller dams that could not be classified than the higher rainfall area. In other words the higher rainfall area have more dams with big surface area that could easily be classified, compared to the low rainfall area. The other reason might be that the higher rainfall areas have more dams than the lower rainfall area, due to the fact that it receives better river flow. According to figure y+1 the average size of the classified dams is following the same pattern as rainfall i.e. in the higher rainfall zones the average size of dams is larger and the lower rainfall areas the average size of dams is smaller. This can also be attributed to the river flow. For instance it is viable to build a large dam in the high rainfall area because there is enough runoff to fill the dams.

Figure 10, shows that the sub-catchment in the higher rainfall area has much more vegetation than the lower rainfall area, which corresponds with the results of the surveyed vegetation results (See Chapter: Water and Land use). This can be attributed to the rainfall differences in the sub-catchments. The sub-catchment in the lower rainfall area has more bare ground because of its mountainous topography.

Conclusion

This study has shown that it is possible to map dams using Landsat TM satellite imagery. However the accuracy of the classification is highly dependent on the size of the dams and the topography of the area under investigation. Shadows in mountainous terrain showed to be a problem that has to be further investigated. It is believed that a more stable classification algorithm can be developed, which would improve the accuracy of the classification.

The results showed that dams with an area of less than 900 m2 can not be detected with any precision at all. Dams with an area of less than 10.000m2 are in most cases under estimated while larger dams tend to be overestimated.

Landsat TM proved to be a useful data set for mapping of vegetation. This was confirmed by the finding from the vegetation surveys in the field.

Recommendations

Based on the findings from this study we recommend that Landsat TM is used as a supplement for conventional dam surveying, although the methodology has to be further developed before the results can be used as a support for decision making.

Chapter 5: Basin Management

By: *Angula Herman, Haimbodi Ndeutalala and Nakathingo Hertha*

Introduction

One of the SDP9 sub-groups concentrated on the basin management committee (BMC) especially on the reasons why there is a need for its establishment in the Kuiseb basin. Interviews were conducted and used to collect information about farmers' perceptions and expectations of the BMC.

Why a basin management committee

Chapter 11, Article 100 of the Namibian constitution states that "land, water and natural resources below and above the surface of the land and in the continental shelf and within the territorial waters and the exclusive economic zone of Namibia shall belong to the state if they are not otherwise lawfully owned". The constitution recognizes that the planning and management of water resources requires information systems and institutions operating in an open and transparent manner. The Namibian government is planning to introduce a new draft water bill because the one in use is dated out and not in agreement with the Namibian constitution.

The water resources management bill currently in consultation would provide fundamental reform of the law relating to water resources management to repeal certain outdated laws. Where appropriate the delegation of management functions to a regional or basin level is necessary as so as to enable all people to effectively participate. The new draft water bill has proposed the establishment of Basin Management Committees (BMCs) that will plan and manage water resources effectively within all the basin areas.
Proposed Functions for the BMCs are:

- To promote community participation in the protection, use, development, conservation, management and control of water resources including groundwater areas through education and other appropriate activities
- To make recommendations regarding the issuance of licenses and permits
- To promote community self-reliance, including the recovery of costs for the operation and maintenance and replacement of waterworks
- To facilitate the establishment of an operation and maintenance system of waterworks and accessing of technical support for water use.
- To monitor and report on the effectiveness of policies and action in achieving sustainable water management
- To assist with conflict resolution within its water management area.
- To develop a water research agenda, together with the Water Resources Management Agency, appropriate to the needs of water management institution and water users within its management area.

The new water draft bill is designed to ensure that Namibia's water is well managed, developed, protected and used in a sustainable way to achieve fundamental policy principles set forth in the Namibian constitution. Principles of the draft water bill are as follows:

- Every citizen has a right to equitable access to water to support a healthy and productive life.
- Water is essential for life and safe drinking is a basic human right
- Citizens have the right to obtain, within a reasonable distance from their place of abode , a quantity of water sufficient to maintain life , health and productive activity
- Decision-making should be consistent with the water resources planning process that incorporates economic, environmental and social dimensions
- Water resources information should be accessible to the public and managed in an open, transparent way.
- Water resources should be managed to promote sustainable development
- The economic value of water resources should be recognized and their development must be cost effective
- Water resources decision making should further a process of human development and competence
- The awareness and participation of stakeholders in decision-making must be facilitated and encouraged
- Water resources decisions should be consistent with firm and specific mandates from government that separate policymaking from operational and regulatory concerns (Draft water Bill 2000)

Methodology

To determine the farmers' perceptions of Basin Management Committee, SDP9 conducted interviews with farmers in the higher rainfall area in late 2000 and again in the lower rainfall area of the Upper Kuiseb catchment in January 2001.

Questionnaire design

A group of three students set up questions related to Basin Management Committees. The questions were reviewed by other members of SDP9 and integrated with other questions from other groups. In addition to questions, a short paragraph was prepared to provide information for farmers not familiar with the idea of a Basin Management Committee. The questionnaire is included as an appendix.

Interview process

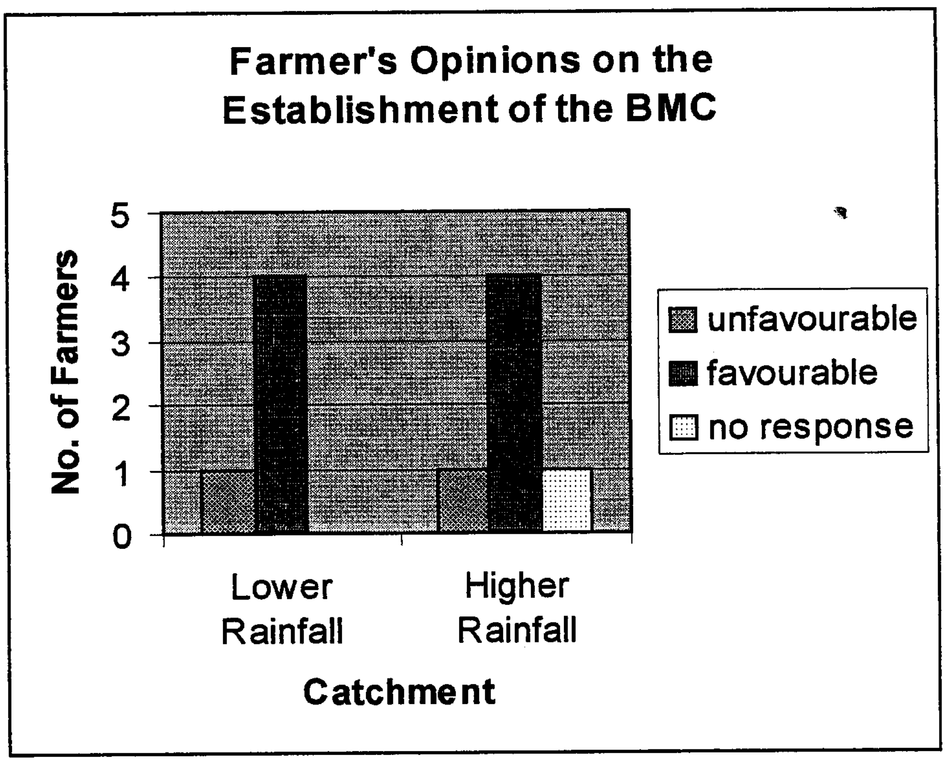
A group of 4-6 students conducted each interview. Before farmers were interviewed about the BMC, a short introduction was made to brief them on the issue. One person asked questions and the rest recorded responses. After the interview was finished the recording group compared their recorded responses.

Data analysis

All questionnaires were collected and data was entered in the computer and a summary sheet was formulated to ease interpretation and comparison of responses from different farmers. Data were summarized for the higher and lower rainfall sub catchments. The findings were discussed among students and Gobabeb Training Research Center staff members.

Results of the basin management committee analysis

In the higher rainfall area four out of the six interviewed farmers were aware of the new draft water bill, one has not heard of it. In the lower rainfall areas, one of the five farmers was aware of the new draft water bill. Four out of six interviewed farmers in higher rainfall area reported that they feel that the Basin Management Committee should be established. In the lower rainfall area four out of five farmers feel that Basin Management Committee should be established.



Two out of 6 farmers in the higher rainfall area suggest that the Farmers' Union Representatives (e.g. Gamsberg farmers' Union) should manage the committee. One suggests NAPCOD and the other three suggested that experts or farmers themselves should be involved in the management of the committee. One farmer was not willing to be involved in the management of the committee but would like to give advice. Two out of five farmers in the lower rainfall area feel that the Department of Water Affairs and one farmer feels that the Municipality should manage the committee. The rest did not respond.

The following are the farmers' expectation from the Basin Management Committee:

- Better communication between farmers and relevant organizations
- BMC should manage the area according to the farmers' needs
- BMC should deal with conflicts among farmers
- Get the people together to discuss their problems
- Mining is taking a lot of water so there is a need for the committee to resolve water problems among water users
- Provide enough water to farmers and livestock

Conclusion

Although farmers support the establishment of a basin management committee they are curious to know more about it. If farmers had adequate information on the new water draft bill especially on the Basin Management Committee, then responses might be different. However it seems that even if farmers support the establishment of a committee their willingness to participate in the management of the committee is low, because of time constraints. It is worth noting that even the farmers who didn't hear of the new draft water bill were positive about the establishment of the basin management committee.

Since the basin management committee is aimed at promoting decentralization and capacity building and also promoting sustainable use of scarce natural resources, SDP9 participants support the establishment of this committee.
In addition the Gobabeb Training Research Center supports and is interested in becoming a member of this committee and is willing to contribute to information gathering and for promoting better management practices.

One of the findings in this study is that only 5 of the 29 dams surveyed have capacities larger than 20 000m3. All others are below that capacity. This in contrary to the Department of Water affairs' general assumption that there are many farm dams with capacities larger than 20 000m3. This means that farm dams may not have as great an influence on the water balance in the Kuiseb Basin as originally believed. Specifically in high rainfall years these dams have no significant influence on the water balance. If this information becomes known there should be less conflict between the water users in the Upper and Lower Kuiseb catchments.

RECOMMEDATIONS

- More information is needed by farmers about the basin management committee before its establishment to give farmers a clear picture of what to expect from it. We therefore recommend an awareness campaign to inform the farmers and all the concerned water users about the new draft bill and in particular about the Basin Management Committee.
- Even if farmers are not interested in the management of the committee they should be consulted for advice on matters concerning them.
- The Basin Management Committee should put more emphasis on problem solving among the water users or between the public and government.
- More farmers' opinions on Basin Management are needed to cover a range of perceptions from a reasonable number of farmers.

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Appendices

Appendix 1: Use of remote sensing for mapping of farm dams and vegetation

Introduction

Geographical Information Systems (GIS) are based on digital maps (maps that can be altered in the computer). Thematic layers like soils; vegetation, rivers and dams are all on separate layers or themes. By combining overlays, different thematic maps can be created. There are two types of GIS : Vector GIS and Raster GIS which links to remote sensing. Vector GIS is based on points, lines and polygons (areas). With these three types we can describe any feature on earth. Raster GIS maps on pixels (grid). All layers have the same number of columns and rows, which makes it easy to compare different themes by using map algebra, e.g. (theme 1-theme 2). The raster GIS is built on the same concept as satellite images. This makes incorporation of satellite images into the analysis simpler.

Remote sensing is a tool to look at features on the ground (land surface) via satellite images. Satellite images and air photos are known as raster images and are in the form of grids or matrices of points or pixels. These points are arranged like rectangular cells in rows and columns each having a numerical value relating to the reflected light transmitted from the area on the ground covered by the pixel. Raster images may have one or more bands or channels of information. These bands represent different wavelengths of detectable radiation in the electromagnetic spectrum. The image uses an arbitrary colour scheme to indicate different data values; for example, Landsat TM has seven bands ranging from Visible blue to Infrared. Normally 3 bands are viewed at a time by using Red, Green, and Blue colours, generating a true colour picture.

A classification process is typically used to process satellite imagery. It is used for interpreting and identifying areas. It allocates pixels in an image an arbitrary numerical value to represent classes or areas of interest. There are two types of classifications: Unsupervised and Supervised classification. Supervised classification is based on training areas. This classification assumes that the imagery of a specific geographic area are collected in multiple regions of the electromagnetic spectrum, but it can also be applicable to other types of imagery. In Supervised classification the identity and location of a feature class (For example, water, vegetation, urban areas etc.) are known beforehand through fieldwork or other means. The known features can be identified on multi-spectral imagery to represent training areas. Training regions are vector polygons that define an area of interest in an image and are used for determining the spectral signature of each class (i.e. dams, vegetation types etc.). Training regions are also used to display parts of an image separately from others or for masking out parts of an image for mosaicing.

The spectral signature of each class defined by the training regions is analysed for each band or a combination of bands by using histograms and scattergram. A scattergram is a graph showing the correlation between two bands of data in the same image. The value of each point on the scattergram is a count of the number of times a specific combination of values for the two inputs

occur. Scattergram can be used to validate training regions, create new regions or create vector regions to display the scattergram on a map.
By studying the position of the classes defined we can determine what band combinations should be used for the classification.

A Histogram on the other hand is used when there is more than one layer of the same type, like two green layers, and you want both to have a similar contrast and brightness. Display histogram only enables you to look at an output histogram of the data at a specific point of the processing. Histograms are used to highlight a class where a quick view of outstanding data in spectral space is obvious.

Vegetation Indexes

Vegetation indices have become a conventional means by which image processing can provide accurate estimates of biomass, the Normalised Difference Vegetation Index (NDVI) has been widely correlated with green biomass and its sensitivity to soil background and to atmosphere except at low plant cover. It's used to take a quick qualitative look at the vegetation cover in an image. Vegetation is usually shown in red by remote sensing because the human eye perceives the longest visible wavelength to be red and the shortest visible wavelength to be blue. This is an incentive for remote sensing images to be set up so that the shortest wavelength is shown as blue and the longest one is shown as red. Usually a near -infrared is the longest wavelength being displayed. Since vegetation is brightest in the near infrared, vegetation turns out red

Linear regression relationships between NDVI vegetation and rainfall in Etosha National Park of Namibia has been studied (Du Plessis, 1999). Satellite derived NDVI and MVC (maximum value composite) are potentially very useful tools for the frequent monitoring of effective rainfall and green vegetation cover or biomass over large areas. The NDVI and MVC may therefore be ideal tools for monitoring changes in vegetation during the rainy season which could contribute to more objective animal, water, vegetation and fire management in Etosha. The NDVI is determined by the degree of absorption by chlorophyll in the red wavelengths, which is proportional to leaf chlorophyll density and by reflectance of near infrared radiation (Tucker et al, 1985).

The NDVI has been empirically shown to relate strongly to green vegetation cover, i.e. healthy vegetation, and biomass by using ground-based studies involving spectral radiometers (Boutton and Tieszen, 1983). A problem with using NDVI is that the index is seriously disturbed radiometrically due to complex radiative interactions between the atmosphere, sensor view angle and solar zenith angle (Van Dijk et al, 1987). In areas with low vegetation cover the NDVI is less efficient due to a strong influence of the underlying soil. These factors reduce the reliability of NDVI in arid environments as in Namibia.

According to studies done by Boston and Teisan (1983) it was found that during the rainy season, both vegetation and NDVI values increased, and then decreased towards the end of the rainy season (middle of April 1995). The NDVI has been shown in the literature to relate strongly to changes in green vegetation or vegetation with a low green cover (Boston and Teisan, 1983).

Remote sensing systems and techniques have been shown to be capable of mapping the spatial vegetation status and its dynamics (Kennedy, 1989). Earlier attempts to assess vegetation cover in the eastern Mediterranean area using remote sensing techniques have been conducted by Ottoman and Tucker (1985). A Landsat MSS imagery was utilised to examine the anthropogenic impact on the vegetation cover and surface albedo in the northern Sinai area. Monitoring vegetation on regional and global scales is one of the major applications of remote sensing. The separation between vegetated and non-vegetated areas is based on the use of reflectance values.

Vegetation is differentiated from bare surfaces due to sharp differences between the red and infrared reflectance of light received by the satellite sensor. Existing methodologies for vegetation monitoring, including those based on the NDVI were found to be limited in describing biomes and percentage vegetation cover, especially at low density cover (Seller, 1985). Remote sensing techniques for vegetation monitoring are based on modelling the physical relationship between vegetation and reflectance and application of the model to satellite data to map the regional vegetation properties (with, for example, a resolution of 900 m2 in the case of Landsat TM). There are several techniques for measuring vegetation cover in the field. A common procedure is simply to apply a visual estimation of the percentage of ground covered in a quadrant. Visual assessment is used twice in the field methods: Firstly to determine the vegetation cover for small patches and secondly for extending the values determined at the individual patches to the areas around them.

There is a tendency in many field surveys to characterise the vegetation in soil patches, thus avoiding for example areas with dense rock and stone cover. Remote sensing on the other hand provides large regional cover where image pixels may be affected by mixtures of all the possible spatial components and thus may present lower vegetation cover values than those found by field surveys. Field surveys of vegetation mainly utilise human visual judgement. Satellite data provides mainly viewing from above and the interpretation methods are basically objective and consistent. The cost effectiveness of remote sensing methods allows frequent assessment of the vegetation cover distribution. Equivalent field surveys would require much higher costs and longer time spans, thus limiting repetition within and between years. The pattern of vegetation cover dynamics is linked to short- and long-term geomorphic pedogenic processes investigated within an integrated research of climate, vegetation and erosion along a climatological gradient (Lavee, et al, 1993).