Land Cover Changes in Montane Cloud Forests in Kenya and Their Potential Impacts on Water Availability-Similarity to Saudi Arabia

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Abstract: Africa had lost 16% of its forests and 5% of its woodlands and grasslands over the period of 1975-2000, equating to over 50 000 km^2 per year of natural vegetation. Besides the continental scale studies of land changes, many forest or land-cover-change studies in East Africa indicate intensified land use pressure, evidenced by the loss of forests or bush lands after the 1950s. Most of the land change is associated with clearance of natural vegetation for croplands. The loss of natural vegetation has its consequences to radiation balance of the land surface, biodiversity, water resources, regional climate, vulnerability to soil erosion and livelihoods of human population. This study highlights the results of a study of land cover changes in the Taita Hills in south-eastern Kenya since 1950s and potential impacts of the land cover change on water availability. In the discussion part, a similar setup in Western Saudi Arabia is presented.

Key words: Land cover ⋅ Water resources ⋅ Remote sensing ⋅ GIS

INTRODUCTION

Land Cover Change in Sub-saharan Africa: Africa had lost 16% of its forests and 5% of its woodlands and grasslands over the period of 1975-2000, equating to over 50 000 km^2 per year of natural vegetation. Most of the land change is associated with agriculture: between the years 1975 and 2000 the agricultural areas increased 57% in sub-Saharan Africa [1]. Also natural land cover change may exist due to changes in precipitation pattern or fires [2], which may foster human populations to seek arable land elsewhere or to change their farming practices or crops [3, 4]. The forest loss is especially hard on areas with high biodiversity and in the Afromontane areas, where the decrease is estimated to be 3.8% annually according to [5]. Besides the continental scale studies of land changes, many forest or land-cover-change studies in East Africa indicate intensified land use pressure, evidenced by the loss of forests or bush lands after the 1950s [6-10]. This study highlights the results of a study of land cover changes in the Taita Hills in south-eastern Kenya since 1950s.

Study Area

The Taita Hills Are Islands in the Sea of Savanna: The verdant and humid Taita Hills offer a unique venue for land change studies as it is located on the dry Tsavo plains between the Tsavo East and West national parks districting the human population and agricultural lands to expand naturally to the plains. The hills cover an area of 1000 km^2 and are surrounded by semi-arid *Acacia/Commiphora* shrubland and dry savannah. Whilst the surrounding plains are at an elevation of 600-900 m a.s.l., the Taita Hills rise abruptly in a series of ridges with the highest peak of Vuria at 2208 m, although the average elevation of the hills is 1500 m (Figure 1). The climate is influenced by the Inter-Tropical Convergence Zone (ITCZ) which leads to a bi-modal rainfall pattern, with long rains during March-June and short rains in October-December, although the annual variability of precipitation is high. Located 150 km from the Indian Ocean orographic rainfall plays an important part in the local climate as the hills form the first significant barrier which moisture laden air encounters. Mist and cloud precipitation occurs throughout the year;

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Fig 1: The plains in the front of the Taita Hills are at 950 m a.s.l. in the south-west, while the highest peak Vuria in the middle reaches 2208 m a.s.l. (P. Pellikka, 2012).

consequently, whilst the annual rainfall is circa 600 mm on the plains it is over 1200 mm in the hills [11]. A rain shadow effect is discernable on the north western side of the hills, with the distinctive *Euphorbia candelabrum* and more commonly *Euphorbia bussei* var. *kibwezensis* growing in the drier conditions.

In prehistorical times, the Taita Hills may have been covered by hundreds of square km of indigenous rain forests, but due to its favourable climatic and edaphic conditions, the forests have been cleared for agriculture for long ago. Many authors take as granted that one % of the forests remain, but none seem to know how this one % is derived or by who. The degradation and fragmentation of the forests was noted early [12], with observations that the slopes were cleared for agriculture up to the head of all streams. Large-scale decreases in forest cover were caused by railway construction and traffic in early 2000th century and before the introduction of the black wattle (*Acacia mearnsii*) for the tannin industry, the overall tree cover may have been at its lowest. Exotic trees such, as cypress (*Cupressus lusitanica*), blue gum (*Eucalyptus* spp.) and pines (*Pinus* spp.) were introduced between the 1960s and 1980s and *Maesopsis eminii* and silver oak (*Grevillea robusta*) during the late 1970s and 1980s. While eucalyptus, pine and cypress were planted for wood production, silver oak was planted within the fields to support farmers with building material and to decrease the pressure on the indigenous forests. The conservation of indigenous forests began in 1977 by Presidential decree banning the cutting of indigenous forests without a license [13]. Based on the visual analysis of the airborne remote sensing data of the 1950s and these days and landscape photographs taken in 1924, 1957 and 1992 [14] the Taita Hills is characterized by small exotic plantations among intensive agriculture with terraced fields in 1990s and 2000s, while during 1950s terracing was almost

absent and a significant part of the land in the hills was used as pastures. Even though there were more indigenous bushland and small forest patches during 1950s, there were practically no trees on farms.

The Taita Hills is also part of a very important biodiversity hotspot. It is the northernmost part of Africa's Eastern Arc Mountains, which have been identified as one of the top ten biodiversity hotspots in the world and with over 90% forest loss during the last 200 years, the hills rank among the most threatened sites of it [15]. The Taita Hills continue to boast an outstanding diversity and endemism of flora and fauna [11]. Of particular scientific and conservation interest are the indigenous forest patches. Today, only a small amount of native forest remains, occurring in a scatter of four larger hilltop remnants and further much smaller fragments embedded in a mosaic of human settlements, small-holder cultivation plots and plantations of exotic tree species. The indigenous forest cover has been termed upland moist or mist forest by [11], but is also referred to as montane forest or cloud forest by other workers. These indigenous cloud forest patches also play an important role in both capturing additional moisture and storing the precipitation on the hilltops.

The population of the whole Taita-Taveta district has grown from 90 000 persons in 1962 to over 300 000, consequently this has been a driving factor behind the land use change in the Taita Hills. There has been an increase in the area under cultivation and due to poor agricultural management, erodible soils and rough topography in the hills, the foothills are subject to land degradation and soil erosion [16]. The remnants forests are threatened by encroachment (for settlement, agriculture and livestock grazing), extraction of firewood and building materials, poor enforcement of government policies and regulations and lack of awareness among the communities living adjacent to forests, fires and

colonization by suppressive and fast growing exotic tree species [17]. The situation in the Taita Hills, however, is not hopeless compared to neighbouring Sagala Hills some 20 km apart.

Because of its unique biogeographical history, the Taita Hills has been under research during the last decade concentrating on the impact of forest fragmentation and degradation on different components of biodiversity [18], forest health monitoring [19] and population ecological and genetic studies on bird-, mammal-, amphibian- and insect species [20]. University of Helsinki has been studying the land cover changes of the Taita Hills first time in late 1980s, but more intensively since 2003. The main objectives have been to develop methodologies for land cover change studies applying remote sensing and geographic information systems (GIS), to assess the land cover changes in the Taita Hills and its surrounding lowlands and finally, to research the consequences of land cover changes to climate, water resources, biodiversity and livelihoods. Located in the middle of the Tsavo plains and having its small water towers (Ngangao, Vuria, Chawia, Mbololo and Yale), the Taita Hills is like a miniature of Kenya and serves as a model for land cover change in Kenya.

MATERIALS AND METHODS

Land Cover Change Studies Using Two Scales: Land cover change studies have been carried out in two scales. In the fine scale study, airborne remote sensing data was applied to study the forest cover changes between 1955 and today in the Taita Hills, whilst in the coarse scale multispectral SPOT XS satellite imagery have been applied to study land changes between 1989 up to today in the surroundings of the Taita Hills.

Black and white aerial photography used in the fine-scale study was acquired during January-February 1955 by the Survey of Kenya at a scale of 1:30,000. The prints were scanned using a resolution of 14 mm resulting to ground resolution of 46 cm. The colour airborne digital camera data was acquired during January 2004 using NIKON D1X colour digital camera equipped with a 14 mm lens producing approximately 40 cm ground resolution. The individual frames were mosaicked to a seamless orthorectified image mosaic using Enso MOSAIC software in which the aerial photographs of 1955 were co-registered [10]. The land cover of Ngangao, Chawia, Fururu, Macha, Mwachora and Yale forest fragments of the Taita Hills was classified visually on a computer screen using 2004 data producing eight forest classes (indigenous, eucalyptus, pine, cypress, silver oak, black wattle, mixed exotic and bushland) and eight other classes (rock, built-up, water, agriculture, wetland, barren land, agroforestry and heathland dominated by giant heather (*Erica mannii*). The class structure was recorded using the Land Cover Classification System (LCCS) which is a standardized classification system developed by the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme [21]. In 1955 no exotic plantations except black wattle existed in the area and therefore the 1955 data was classified into indigenous forest, rock, bushland, heathland and barren land classes only. The land cover model was created in ArcGIS, from which the area for each land cover class was summed. The area of the indigenous forest of each fragment and total forest area including indigenous forest, exotic forests and bushlands were recorded. The change detection was analyzed by the areal change, percentage change and also by change trajectory analysis [10].

The SPOT XS satellite data used were from July 1, 1987, March 25, 1992 and October 15, 2003 with a 20 m pixel resolution and green, red and near infrared (NIR) spectral bands. All images represent dry conditions, despite the non-anniversary dates and share very similar off-nadir sensor view angles. Besides orthorectification and co-registration atmospheric and topographic effects affecting reflectance characteristics were removed [9]. LCCS was applied to record the following classes: cropland, shrubland, thicket, woodland, exotic forest, broadleaved closed canopy forest (indigenous rain forest), grassland with scattered shrubs and trees, bare soil and other unconsolidated material, built-up area, bare rock and water. For the initial classification, an object based segmentation algorithms of Definiens were applied. The accuracy for the 2003 data was assessed in the field work and with the airborne remote sensing data of 2004. An overall accuracy of 89% was reached after manual editing [9].

A geospatial database containing layers such as road network, hydrography, administrative borders and digital elevation model (DEM) was generated from a scanned topographic map of a 1:50 000 scale of the Survey of Kenya. The resulting DEM had 20 meter raster in a Transverse Mercator projection with a Clarke 1880 spheroid and Arc 1960 datum and a planimetric accuracy of 50 m with an altimetric accuracy of 8 m [9]. Mean monthly precipitation surfaces were produced from monthly rainfall records of 11 stations within the Taita Hills from 1987 to 2005 obtained from the Kenya

Meteorological Department [21] and soil information was derived from Exploratory Soil Map of Kenya of scale a 1:1 000 000 [22].

Using the results from the land cover classification of satellite imagery and additional datasets the soil erosion potential of the Taita Hills were assessed using the Universal Soil Loss Equation (USLE) [23]. The parameters required by the USLE are rainfall erosivity factor (R), slope-length and slope-steepness factor (LS), soil-erodibility factor (K), cover-management factor (C) and support practice factor (P) for its application. Rainfall factor, slope factor and soil-erodibility factor are estimated using rainfall data, digital elevation models (DEMs) and soil maps, respectively. A support-practice factor is applied if man-made soil-control infrastructure is used in the study area. In this study support factor was used as a constant value and cover-management factor was derived from land cover classification using the SPOT XS imagery [21]. Using the remote sensing data the forest cover changes of the indigenous forest fragments between 1955 and 2004 were studied, the land cover changes in the Taita Hills and its surroundings were studied between 1989 and 2003. The results were used also for simulating agricultural expansion scenarios up to 2030 in the study area using spatially-explicit model of landscape dynamics [24] and also to model soil erosion potential changes from 1989 until 2030 [25].

RESULTS

Loss of Indigenous Forests in the Hills and Agricultural Expansion in The Lowlands: The results of the fine scale assessment indicate that the indigenous

Table 1: The change of non-forested area to forests in hectares between 1955 and 2004 in selected study areas in the Taita Hills.

Change from 1955 to 2004	to indigenous forest	to exotic forest
Chawia	3.2	9.2
Fururu	4.1	45.1
Macha	1.7	23.8
Mwachora	1.0	10.1
Ngangao	12.0	81.5
Yale	11.1	94.2
Total	33.1	263.9

forest in the Taita hills decreased by 50% (260 ha) between 1955 and 2004, but the total forest cover area decreased only by 2% due to the establishment of exotic plantations [10]. Each individual forest fragment, however, was managed differently during this time period. The indigenous forest decreased in Chawia, Fururu, Macha, Mwachora, Ngangao and Yale by 28, 76, 78, 68, 20 and 70%, respectively (Table 1). Based on the change detection results, the indigenous forest was changed to agricultural areas, but also to some extent to exotic plantations. The exotic plantations were typically established in barren and dry areas, but also in forests and on agricultural areas. In total 264 ha of non-forested areas were changed to exotic plantations, while 33 ha were converted to indigenous forest. The conversion to indigenous forest is mostly caused by fast growth of succession species as *Phoenix reclinata* on abandoned open areas, but in places, as at the top of Ngangao primary indigenous forest have developed in areas, which were non-forested in 1955. The change of the Ngangao forest is presented in Figure 2.

As a result of a coarse-scale study, the croplands covered 239 km² in 1987 in the Taita Hills and its surroundings, but the area had increased to 244 km² by
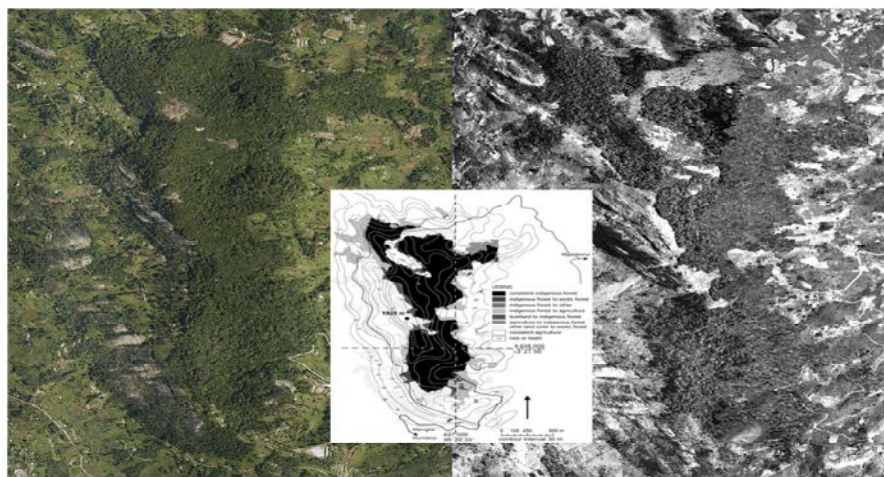

Fig 2: Airborne digital camera image mosaic of 2004 on the left and aerial photograph of 1955 on the right. In the middle is analysed change in which the black colour indicates constant indigenous forest from 1955 to 2004.
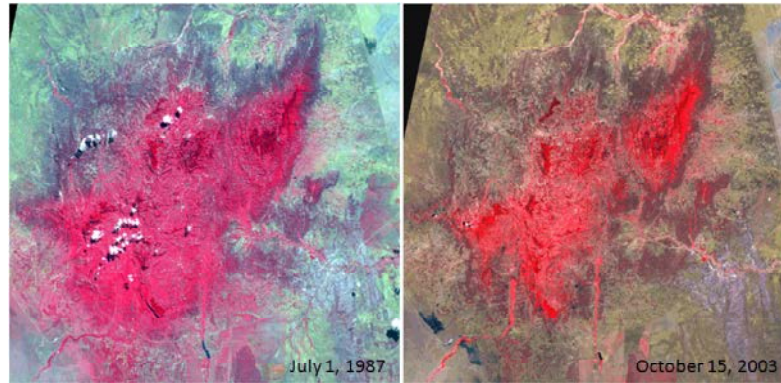
Fig 3: The SPOT XS image of July 1, 1987 taken at the end of the long rains represents completely different greenness compared to the image taken on October 15, 2003 after the dry season. The evergreen indigenous forest patches are much more visible from the landscape during the dry season when the fields are bare.
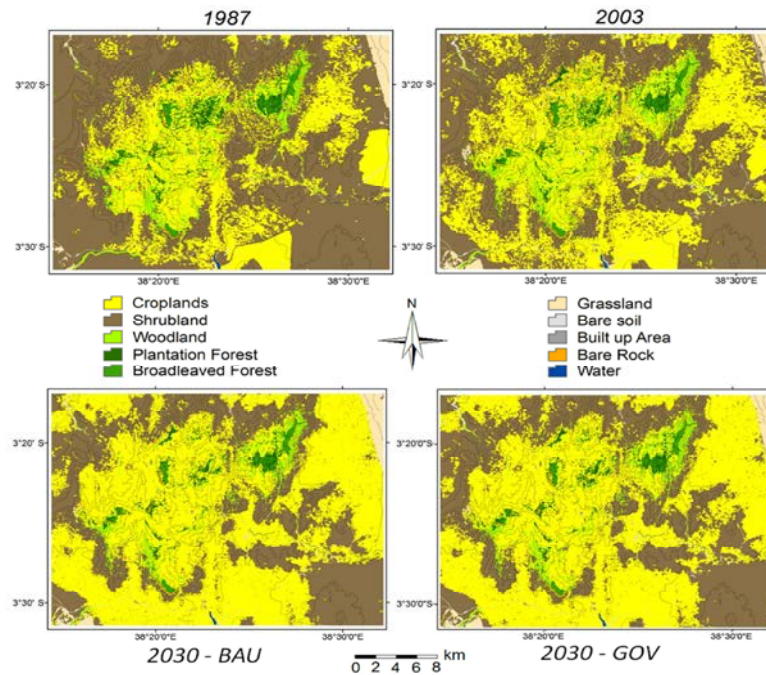

Fig 4: Land use maps for 1987 and 2003 (upper left and upper right) and simulated scenarios for 2030 (lower left and lower right).

1992 and to 331 km^2 by 2003 [9]. This increase was caused mainly by conversion of thicket and shrublands to croplands in the lowlands and foothills. Grasslands increased by four km^2 by conversion from shrublands, especially between the years 1992 and 2003. Plantation forests increased in area, which may be caused by a maturing of the stands, increased biomass and consequent improved identification in the classification process. There was no important change in the area of broadleaved closed-canopy forests (indigenous forests) between 1987 and 2003 in the main three fragments of Chawia, Ngangao and Mbololo. The large increase in bare

soil may be partially caused by phenological effects, since the 1987 image was taken in July after the rainy season, while the 2003 image was taken at the end of the dry season (Figure 3). However, by applying an object-oriented classification method, misclassifications were reduced to as low a level as possible. The decrease in water is mainly caused by the decrease of the water surface in the Mwatate reservoir due to silting of the reservoir.

The land cover change scenario is presented with the historical land use maps for 1987 and 2003 in Figure 4 [24]. The land use for 2030 is resulted from two land cover
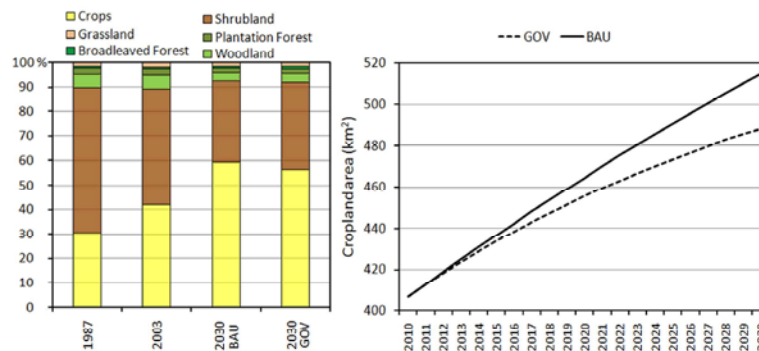
Fig 5 (a): Percentage of the main land use/land cover classes during the years 1987, 2003 and in both scenarios simulated for 2030; (b) LUCC simulation results from 2010 to 2030.

change scenarios: unrestricted business as usual scenario (BAU) and restricted land cover change scenario (GOV). It is observed that, in 1987, croplands were already clearly established in the highlands. The protected areas, situated in the northeast (grassland area) and southwest parts of the study area were effective in containing the agricultural expansion between 1987 and 2003. The influence of this variable was reflected in both simulated scenarios, where a clear boundary constraining the expansion of croplands is observed in the limits of the protected areas. Hence, although a high environmental pressure is present along the fringes of the conservation areas, such as Tsavo East National Park, the areas inside the park are likely to be preserved.

Between 1987 and 2003, croplands started to be implemented with higher intensity in the lowlands, given that suitable areas for agriculture activities in the highlands were already almost entirely taken. Although each simulated scenario was created independently, using different transitions rates, the spatial distribution of new cropland patches followed the same patterns in all simulations. As suitable agricultural areas in highland disappeared, the expansion of new patches was distributed in the foothills. Based on the explanatory factors [24], among the main driving forces of such distribution were the distance to markets (here represented by villages or towns), distance to roads and distance to rivers. Distance to markets and roads played an interesting role in croplands distribution, in the sense that the effects of these two variables in the landscape dynamic were closely related. Towns and villages acted as core points, which are interconnected by roads creating axes in which new cropland patches were settled. Such patterns were observed mainly in the southern and south-western parts of the study area. It is also important to notice the enhanced importance attributed to rivers in the land use dynamic. Given that in this region the foothills

typically have higher average temperatures and lower precipitation volumes, the proximity to water bodies is essential to the establishment of agricultural activities. The numerical results of the simulations are presented in Figure 5. In the BAU scenario, the cropland areas expanded to around 515 km2 in 2030, corresponding to about 60% of the study area representing an increase of 40% in comparison to the year 2003, when croplands occupied around 365 km^2. Although the effects of the governance scenario cannot be easily identified in Figure 4, the simulated land use policies resulted in a significant reduction in agricultural expansion. The total area used for agriculture in 2030 for the GOV scenario was approximately 485 km^2.

The land cover changes have direct impact on the cover/management C factor of the USLE model. Previous studies have shown that croplands increase soil exposure to weathering more than original vegetation such as forests or shrublands. For this reason the C factor of agricultural areas are usually higher, resulting in increased soil erosion rates. The C factor values presented in [21] indicate that average C increased 10% from year 1987 to 2003. In the LUCC simulation for the year 2030, C increased by 9 % from 2003. The areas with higher slope values are likely to undergo higher soil erosion rates and when new fields are located in steep slopes is the soil erosion potentiality even greater. Fortunately, this is not the case in the Taita Hills. Agricultural patches established in the last decades were mainly settled in areas with favourable topography. This pattern was reinforced after 1987, when the availability of space in the hills was scarce and the agriculture started expanding to flat areas along the foothills. In the agricultural expansion simulated for 2030, a slight increase in cropland patches has occurred in steeper slopes, however, the most significant increase has occurred again in areas with gentle slopes or even flat lands.

DISCUSSION

Endangered Ecosystem Services: Land cover change has numerous ecological, physical and socioeconomic consequences. On the positive side agricultural expansion may increase food production for a growing population, although it is unsure how productive the last exploited lands will be as they are typically the least favourable. There are numerous negative consequences with both known and unknown links and feedback mechanisms.

Converting the natural vegetation to agricultural land is likely to change the radiation balance of the given unit of area. In principle, the albedo increases as land is without vegetation at least part of the year causing more solar energy to reflect back to the space. Moreover, the water holding capacity of the land may decreases as the replacement of trees, bushes, epiphytes and herbs, grasses, mosses or lichens in favour to agriculture cause soil compression reducing porosity and infiltration capacity. In mountainous areas the conversion of the forests to agricultural lands decreases also the occult precipitation as croplands capture less atmospheric moisture than multilayered indigenous forest or forest of any kind [26]. Cloud formation over the land unit also decreases as the evapotranspiration rate is less from fields than from forests causing evidently reduced precipitation. Further studies project that, by 2030, agricultural land are likely to expand to regions with higher evapotranspiration potential (Fig. 6). This expansion will increase by approximately 40% the annual volume of water necessary for irrigation [27].

As soil water holding capacity is reduced, the risk of hydrological droughts during dry seasons is increased, while during the rainy seasons soils are more susceptible to erosion. These soil-loss and sediment-deposition processes may have a significant impact on agriculture, local economies and ecosystems [28].

Although increasing evidences indicate that anthropogenic changes in the landscape are likely to lead to regional and global climate change, the levels and scale of this relationship remain largely unknown. However, it is clear that converting forest land to agricultural land causes changes in local climate via the changes in radiation and water balance. Changes in precipitation and temperature patterns will likely have important impacts on the sustainability of agricultural systems. The land cover change taking place in the Taita Hills and its surrounding has been continuing since human settlers arrived in the area and started to convert native vegetation to agricultural land. With ever growing population and demand of land for cultivation of food crops and other crop types in addition to increase of reserved and protected areas in the study area, land is evidently becoming a valuable natural resource. Land use conflicts have already taken place in the area between farmers, conservationists, settlers and sisal plantation managers [29].

Converting natural vegetation, forest or grassland to agricultural areas decreases biodiversity, reduces the capability of vegetation to capture atmospheric moisture and retain water in the vegetation cover, exposes land to be subject to water and wind erosion and changes the radiation balance of the land surface as land is exposed and barren part of the year. This all have still unknown impacts on regional climate.

The importance of mountain forests in capturing atmospheric moisture is a well-known fact, but the quantity of this fog deposit or occult precipitation is seldom assessed as it is quite cumbersome task [30]. In Arabian Peninsula, the phenomenon occurs also on the western slopes of Eltharwat Mountains from Taif all the way to the border of Jemen. The climate is influenced both by westerly depressions which bring rain in the winter and spring. In addition, the Red Sea diurnal wind
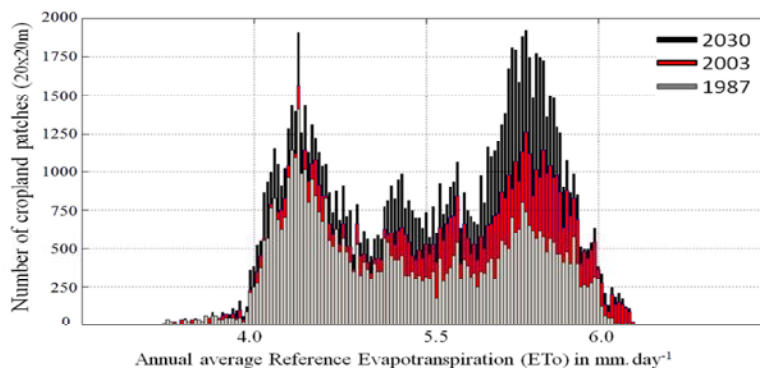

Fig 6: Histogram showing the cropland patches distribution during 1987, 2003 and 2030, in relation to the historical average potential evapotranspiration in the Taita Hills.

Fig 7: Declining juniper forest near Al Bahah, Western Saudi Arabia. About 40% of the trees are without foliage.

circulation brings frequent cloud and foggy conditions to areas above 1000 m [31]. In the Western Saudi Arabian mountains, the forests are built up by juniper species (*Juniperus procera* and *J. phoenicea),* which capture the moisture from the air similarly as the cloud forests in the Taita Hills and maintain the moisture in the vegetation, litter and soil (Fig. 7). The ability to obtain fog deposit is evidenced by the arboreal lichen species growing on the trees in some areas [32]. According to [31] there has been a decline in the health of the junipers at the same time as the juniper forests are cleared for various land uses, like recreation as in the region of Al Bahah. This process evidently have negative consequences on the amount of occult precipitation and well as in the ability to store water resources in the juniper forests and is a focus of further studies.

ACKNOWLEDGEMENTS

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