Radargrammetry helps fight hunger in Ethiopia

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ABSTRACT

This paper reports the operational implementation of radargrammetry for the production of Digital Elevation Models, or DEMs, to areas of rugged topography. The Southern Ethiopian Highlands east of lake Abaya, with elevations between *ca.* 900 and 4,400 meters, were mapped. Currently available topographical maps are of insufficient quality to assist a study of the area's unique land use system, which is arguably the oldest and most durably sustained land use system of the planet. Without external inputs or terracing, the land use system maintains soil fertility and staves-off hunger. It has been doing so during the past 30 years of unrest and civil war, in one of the most crowded regions of Ethiopia. However, the central role of the staple crop enset within the land use system and its production cycles has hardly been the subject of scientific study. Understanding of this system is most likely to be relevant to enhancement of health and productivity in many regions of the world. Upon the request of the Agricultural Bureau for Gedeo Zone, geocoded and georeferenced topographical maps with accuracy of 20 meters (x, y and z) were made by PRIVATEERS N.V. on the basis of RADARSAT multi-incidence (S2/S7) images. These maps are now incorporated as the basic layer within the Bureau's GIS system. Map production techniques proved to be cost effective and relevant; especially for mountainous areas with poor accessability where correct geographic information is not available. The ease of orientation proved of invaluable help to rationalize execution and planning of cost-effective environmental field work and reporting.

1. INTRODUCTION AND SCOPE OF THE RESEARCH

The operational site:

The Gedeo live in the escarpments of the South East Ethiopian Highlands, around Dilla overlooking Lake Abaya in the Rift valley, between *ca.* 900 and 3000 meters above sea level [9].
Their country is located in the humid southeastern Ethiopian highlands, approximately between 5° and 7° North latitude and between 38° and 40° West longitude, 360 km southeast of Addis Ababa. Dating back from neolithic times [27], Gedeo land use systems are among the oldest agricultural systems in the world.
With more than 420 persons per square kilometre, the Gedeo highlands are one of the most densely populated regions in the country [7].

Currently available topographical maps are of poor precision and reliability, thus rendering them of little use to land use planning in the Gedeo zone.

Ensete Ventricosum:

The Gedeo have developed *enset* agriculture which is based on the group-wise use of *enset (Ensete ventricosum*) (see Table 1) [10], the rotation of which is maintained in the context of the larger multiple rotation of the components accompanying *enset* [10,11] (see Tables 2 & 3). The shorter rotation (*enset*) and the longer one (*Coffea arabica*) are interwined in the mixed population of multi-purpose trees with very long, natural rotations, the latter timing the average ecological turnover. Implicit in the rotation of *enset* was the concept of sustainability, showing that the Gedeo had long been aware of the concept of sustainability [9]. This sustainability hence preceded by far the forester Von Carlowitz (1713, from [22]), the first European to have published the German concept of *Nachhaltigkeit, i.e.*, conservation for posterity. Sustainability since long was seen from three angles, *i.e.*, an ecological, a social and an economical one (*eg.* [21,12,6]).

size-class (1)	D_{rc} cm (2)	h m (3)	LN m (4)	LL m (5)	LW (6)	Number (7)	%total (8)
K_2	10-15	0.5-1.0	2- 3	1.5-2.0	0.1-0.3	885	29.5
K_1	15-19	1.0-1.8	3- 6	2.0-2.5.	0.3-0.5	672	22.4
S_2	19-22	1.8-2.0	6- 8	2.5-3.0	0.5-0.8	486	16.2
S_1	22-39	2.0-2.3	8- 9	3.0-3.5	0.8-0.9	285	9.5
G_2	39-41	2.3-2.5	9-10	3.5-3.6	0.9-1.0	165	5.5
G_1	41-43	2.5-2.7	10-11	3.6-3.8	0.9-1.0	138	4.6
B_2	43-65	2.7-3.5	13-15	4.0-6.0	0.8-0.9	126	4.2
B_1	65-100	2.7-3.5	13-15	4.0-6.0	0.8-0.9	123	4.1
D	90-100	3.5-4.0	15-18	5.0-6.0	0.9-1.0	120	4.0
Total						3000	100

Table 1: Complete enumeration and distribution of a population of enset (Ensete Ventricosum (Welw.) Chessman MUSACEAE) over Gedeo size classes and over the 2.5 ha farmland feeding 23 household members altogether. Gedeo size-classes: subscript 1 represents the oldest phase; K = Kaassa; S = Saxxaa; G = Guumee; B = Beyaa; D = Daggicho (for meaning see text). Symbols: D_{rc} = diameter above root collar; H = height of pseudostem excluding leaves; LN = leaf number; LL = leaf length; LW = leaf width.

Enset sustains the highest population density in Ethiopia (420 persons per km^2, in Gedeo province [7]. *Enset* is not affected by excess rain nor by drought, as has been witnessed during the famines of the 1980s [4]. Besides, the stability of the SE Ethiopian highlands owes much to the *enset* culture [1]. Therefore, Brandt *et al* [4] rightly called *enset* the tree against hunger [2,4], while Emperor Menelik's appreciation of the plant saying it was appropriately called *worqe*, literally meaning "my own gold" as it was not affected by the lack of oxen during the Great Famine of 1888-1892 [23], is well placed.

The Gedeo numbering around one million belong to the Eastern Cushitic-speaking group [15,5] and are the people most dependent on *enset* [9], where it is believed to have been the ancient food plant [25]. The history of *enset* is only fragmentarily known, as when, where and by whom was first domesticated not precisely known [25]. Though *enset* occurs in many parts of Africa and Asia [26,4,25], Ethiopia is the only country known for the cultivation of *enset*, in its Southern Peoples' Region.

The Gedeo have developed their own ways of growing and processing *enset*, their livelihood in the steeply escarpments of the SE Ethiopian highlands dependent on it.

Enset indeed is a very versatile crop worth of further research and development, as it is the most unstudied of all domesticated crops in Africa [4]; it is also one of the unharnessed agricultural resources for the erosion- and drought-prone Ethiopian highlands, representing perhaps a viable solution to the recurring food crises.

Species	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-120
Ensete,	x								
Ensete, *Milletia*		x							
Ensete, *Milletia*, *Coffea*			x						
Ensete, *Milletia*, *Coffea*, *Pygeum*				x					
Ensete, *Milletia*, *Coffea*, *Pygeum*, *Albizzia*					x				
Ensete, Milletia, *Coffea*, *Pygeum*, *Albizzia*, *Celtis*						x			
Ensete, Milletia, *Coffea*, *Pygeum*, *Albizia*, *Celtis*, *Aningeria*							x		
Ensete, Milletia, *Coffea*, *Pygeum*, *Albizzia*, *Celtis*, *Aningeria*, *Cordia*								x	
Ensete, Milletia, *Coffea*, *Pygeum*, *Albizzia*, *Celtis*, *Aningeria*, *Cordia*, *Podocarpus*									x

<u>Table 2:</u> The place of enset within the multiple rotations of the agro forest.

Species	Rotation time (years)	Remark
Ensete ventricosum	10	plant yielding staple food
Coffea arabica	30	cash crop
Milletia ferruginea	50	used for soil enrichment, shade and as source of fuel wood & fodder
Cordia africana	70	used as shade & source of construction wood
Croton macrostachys	50	mainly used as source of fuel wood
Pegeum africanum	70	mainly used as source of fuel wood
Albizzia gummifera	50	mainly used for soil enrichment & also as shade
Erythrina abyssinica	30	mainly used for soil improvement & also as shade
Celtis sp.	70	mainly used as source of construction wood
Aningera friedereci	100	source of timber regarded as one of the best
Podocarpus gracilor	120	source of timber regarded as one of the best

<u>Table 3:</u> Estimate of the natural rotation time for some perennial components of Gedeo agroforests.

Scope of the research:

With the foregoing perspectives, understanding of the land use system is of critical importance for the region. This has recently been confirmed in a study by the American Association for the Advancement of Science [2]. The study's title depicts enset as the *"tree against hunger"*. According to the study, enset provides a healthy saple food and simultaneously enhances soil fertility. The study thus reaches the conclusion that: "Research and development are needed to address sustainability issues and the place of enset as a major contributor to the food security of Ethiopia" [4]. Such understanding may well prove to be of fundamental relevance to other densely populated mountainous regions, as was confirmed for the Andean region. If so, the lack of understanding this unique land use system can be seen a hindrance to its beneficial promotion.
Results of the present study will contribute to the better understanding of the land use systems, and will directly benefit an estimated 15 million people dependent on enset cultivation and another 12 million dependent on coffee cultivation, the two major components of the Gedeo land use system. Moreover, the study happens to come at the right moment when general principles from complex land use systems are being considered for possible use in designing stable and sustainable cropping systems fit for the present age (compare [16]).

2. RESEARCH PHASES AND TECHNICAL APPROACHES

The present study use methods that represent the existing land use systems' complexity as fully as possible. The basis of the methodologies is graphical and employs profile diagrams and maps at the appropriate scales (*cf.* [9,22]). The method is complemented with FAO's criteria of land evaluation [8]. Data are collected at two scales, *i.e.* landscape and farm, in three consecutive phases. A Digital Elevation Model (DEM) is used to extrapolate the farm system results to the scale of landscape for the Gedeo zone.

Phase 1 covered a preliminary survey, including a pilot study to check the methodology. Phase 1 was initiated in 1998 by the Director and a team of field researchers at the Agricultural Bureau of the Gedeo Zone. The field work consisted of a general survey, resulting in: lists of land marks and limits to be entered on the map; a selection of 14 farms, two per altitudinal zone, to be the object of the case studies; a selection of "good farming" families or households as sources of local information; and a questionnaire. The agents of the Agricultural Bureau for Gedeo Zone were trained in the approach of farmers for research purposes, proper conduct of sound field interviews, recording of responses and distinguishing and recording of land marks. Supervision was provided by the Director.

Phase 2 covers the extrapolation of these results to a landscape scale. The need for a basic geographic reference map was satisfied by the making a spatio-map, established from geo-coded and geo-referenced RADARSAT Synthetic Aperture Radar (SAR) data of the Gedeo province and a DEM, established by Radargrammetry [13]. This map was prepared by PRIVATEERS N.V. and TREEMAIL. The map is essential to the correct interpretation and extrapolation of the Phase I field research results, and constitutes a sound basis to all future Gedeo Zone mapping purposes.

Phase 3 covers the scale of farms and fields. The basic methodology has been applied earlier by Kippie [9]. Its methodologies and procedures were first described by Oldeman [21] and are meanwhile extensively used, for instance in research on local South-East Asian agroforests or as basic method in the Brazilian programme of research at ESALQ, Piracicaba, Saõ Paulo, on forest fragments of the Atlantic Rain Forest and its management. A simple line transect, proceeding at 400 meters a day, will give the whole farm context with its borders with neighbours. On this transect, plots are pinpointed which represent typical key situations in the sense of land use and/or ecology. These plots are mapped in a more precise way by block transects, including soil and herbarium sampling and the establishment of profile diagrams. Finally, in these plots, key species are to be found, *i.e.* those with a key rotation for the whole set of multiple rotation ("pacemaker species").

Later this year, T.Kippie plans to report the overall phase 1-3 results in Treebook 5 (http://www. treemail.nl/books) and in a Ph.D dissertation for the Wageningen University in the Netheralnds.

3. THE PHASE 2: MAPPING PROGRAM

To achieve the foregoing, farm design and dynamics together with the associated management practices, having in view the level of ecological and socio-economic efficiency attained, will be researched. The manner in which the diverse farm components, farms and land use versions are interacting to give a balanced productivity and stability will be described in terms of agrosystem dynamics and associated management practices. In parallel, trends in the farmers' adaptive strategies across the three land use versions will be documented as these will help both to reflect on their past land use history and in making predictions.

The main task of the present Phase 2 of project is mapping the three altitude-based Gedeo land use systems. In Phase 3, this will allow to assert whether or not changing biophysical factors (along with altitudinal zones) elicit corresponding changes in land use system design, stability, productivity as well as in the farmers' adaptive strategies.

RADARSAT data processing

Radiometric calibration has been performed, according to the RADARSAT SGC product specifications.
The RADARSAT SAR images have been resampled to a pixel size of 20 meters x 20 meters, which corresponds closely to the spatial resolution of the RADARSAT SGC SAR data products.
Conversion from original data format (16-bits per image pixel) to 8-bits per image pixel has been made, in a similar way for the four calibrated RADARSAT SAR images.
Speckle filtering has been carried out using an adaptive Maximum A Posteriori (MAP) speckle filter [14] especially designed for multi-channel SAR images [19,20]. In the Gaussian-Gaussian MAP filter for multi-channel SAR images, new structure and texture detectors [18] based on the second order statistics (autocorrelation properties) of both the speckle and the imaged scene are incorporated.

DEM generation

Using the RADARSAT S2/S7 speckle filtered dataset, a stereo-image has been generated.
Using this stereo-image (or anaglyph), a DEM with a sampling rate of 20 meters x 20 meters has been produced by radargrammetry (see Figures 1 and 2), as described in [13]. This technique has already been used by PRIVATEERS N.V. in the past with satisfactory results [24,17,28].

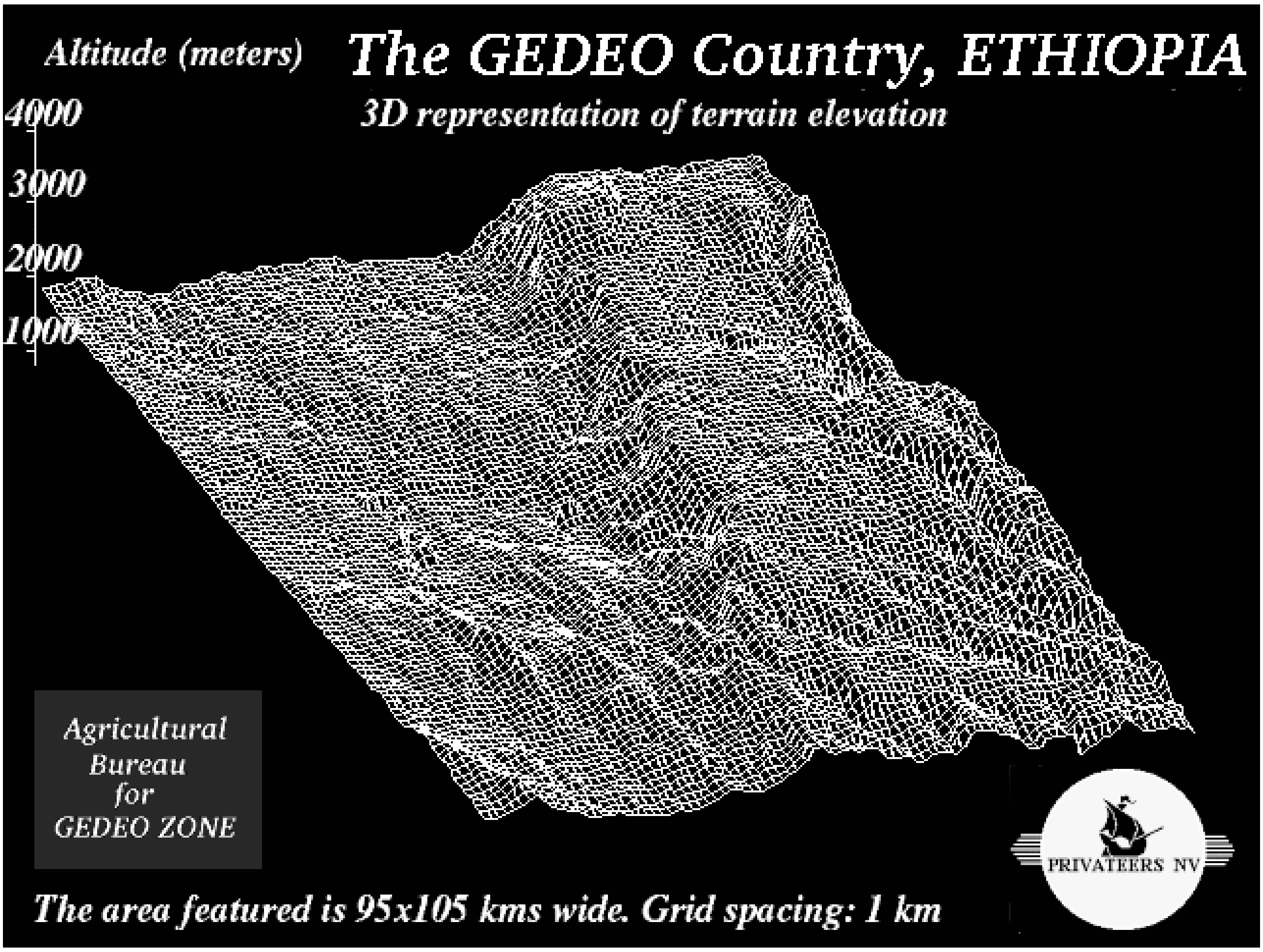

Figure 1: Digital Elevation Model (DEM) of Gedeo Zone (Ethiopia).

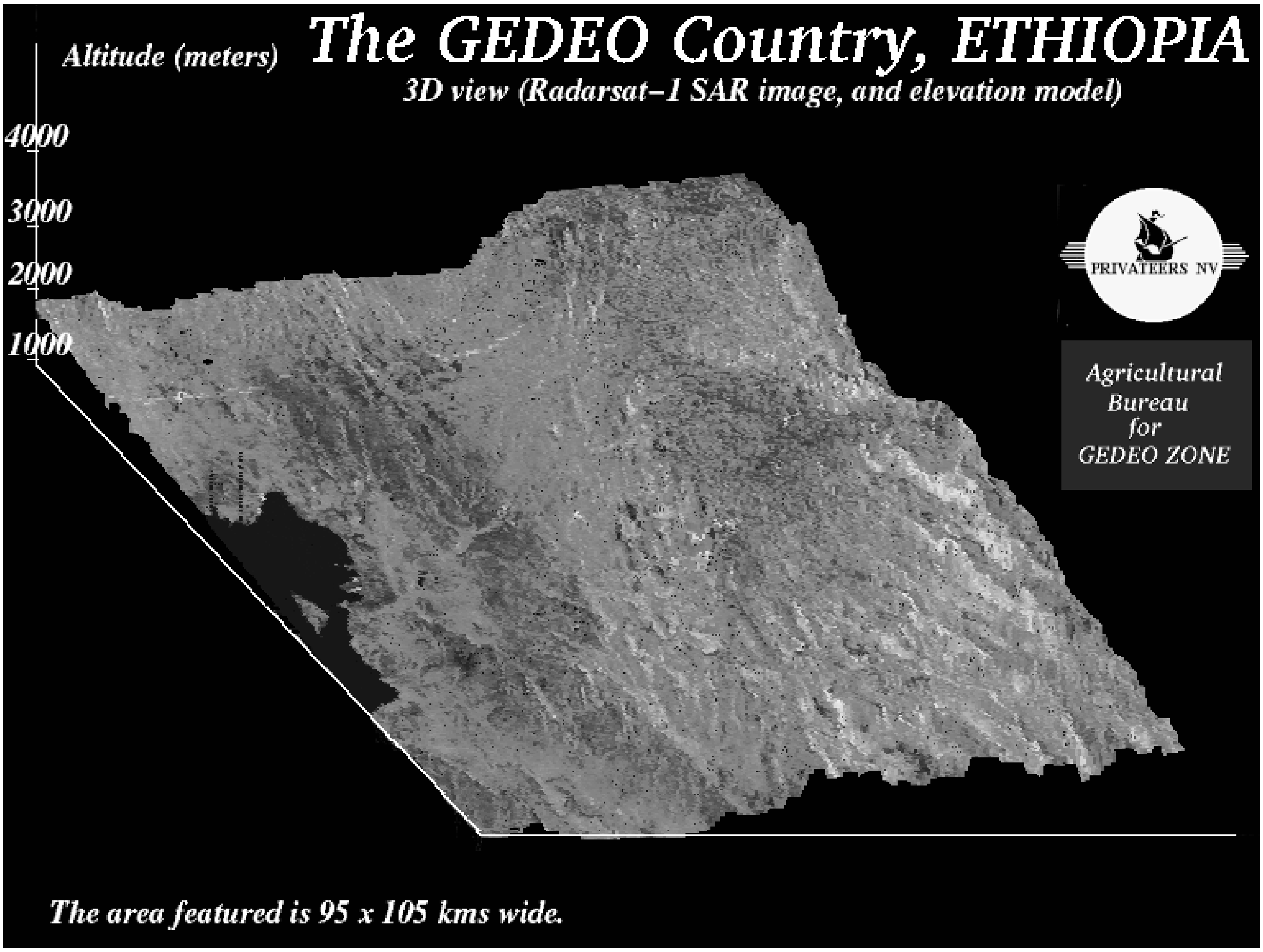

Figure 2: Three dimentional view of Gedeo Zone (Ethiopia). Filtered RADARSAT-1 SAR image and DEM.

Accuracy of the DEM can be evaluated by analysing the results of the geocoding procedure applied to the RADARSAT images. In the present case, the accuracy is of the order of 20 meters in altitude, which is good enough for the purpose of this project (Though some residual wrong altitude evaluations are still locally present in the DEM).
The spatial coverage of this DEM is 10,000 km^2, englobing the whole of the Gedeo Country.
An elevation contour map, every 100 meters altitude, has also been produced, at a spatial sampling rate of 20 meters x 20 meters (see Figure 3).
In addition, the anaglyph is extremely useful for photo-interpretation, in order to understand the thematic contents of the image.

Production of cartographic maps

The speckle filtered images have been geocoded (*i.e.* corrected for the geometrical distorsions due to relief), using the DEM generated previously.
Radiometric Correction for terrain (variation of pixel area, with slope and orientation, influence of actual incidence angle) effects have been applied. The physical model used in the correction for the effects of the actual incidence angle is a Lambertian scattering model [3].

All processed satellite SAR image and elevation products have been projected to Universal Transverse Mercator (UTM), in order to produce cartographic products. The georeferencing system is: Universal Transverse Mercator (UTM), Zone 37, Row N, Earth Ellipsoid WGS 1984 (see Figure 3).

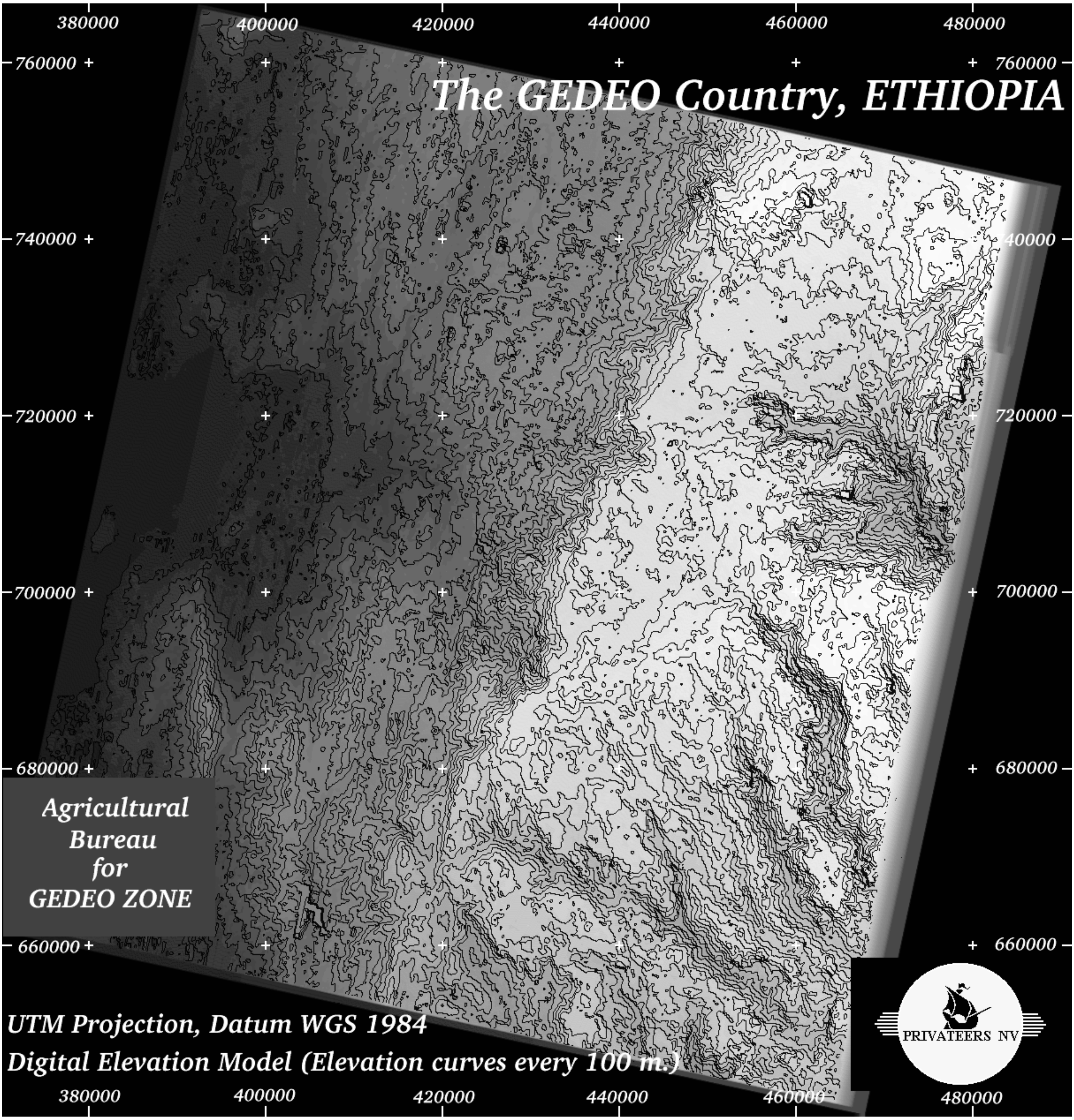

Figure 3: The Digital Elevation Model (DEM) of Gedeo Zone (Ethiopia), in Universal Transverse Mercator (UTM) cartographic projection, with superimposed elevation curves.

4. CONCLUSION

The availability of an accurate DEM enables the study of the rivers coming down from the mountains down to Lake Abaya, and of their watersheds.

Indeed, this continuous elevation information, now available from the source of the local rivers and streams, across all of Gedeo country, and until Lake Abaya, will support in the near future accurate studies of the runoffs, and of the water balance.

It will also support studies aiming at the evaluation of global and local erosion risks in the whole of Gedeo country.

Finally, it will also support studies aiming at the optimization of the management of the water resources or agriculture purposes.

The satellite radar maps, built using speckle filtered RADARSAT SAR images enable the accurate location of the communication network in the Gedeo country. In particular, the only asphalted road running from the Northernmost part of Gedeo country to its Southernmost part is easily indentified.

In addition, the very characteristic response of built-up areas (due to corner effects and/or resonance effects on solid roofs and/or corrugated metal sheet roofs) enables a very easy location of the towns, of the villages, and even of the isolated settlements.

The satellite maps and the DEM, in cartographic WGS 1984 projection, can be used during ground work, with, or even without a GPS (Global Positioning System) device.

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