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Article
A Study of Rock Suitability for Road Pavement Construction

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Abstract:

Like any other infrastructure activity, pavement design requires the use of natural construction materials that meet the specifications for the intended construction works to meet the quality expected.
The study involved prospecting and testing of rocks in Kitui County(Kenya),Kitui Rural Sub-County spanning Kwa-Vonza/Yatta Ward from NyumbaniVillage to Kwa-Kilui in Kyusyani.
This study mainly focused on quarrying rocks in selected sites in Kwa-Vonza/Yatta along Yatta Plateau in Kitui County for a proposed road(Ken Road) from Nyumbani Village to Kenyatta University in Kwa-Vonza. Samples were collected from selected locations and subjected to laboratory testing to determine their physical,chemical and mechanical properties for their suitability in pavement construction.
The properties tested included plasticity index,natural moisture content,bulk density,California Bearing Ratio,Aggregate Impact Value,dry unit weight,Loss Angeles Abrasion Test,Specific Gravity,Sodium Sulphate Solution Test and Water Absorption Test.
The findings show that the identified quarries for stones generally have sufficient quantities for the proposed road works.
With regard to the rock properties,the quarry stones sites meet the requirements of water absorption which should be less than 2% and that all quarry sites meet the requirements for sodium sulphate solution threshold of less than 12%.The dry unit weights and the specific gravity for the stone quarry sites are convergent and averaging at 2.0 with Aggregate Impact Value (AIV) results ranging from very strong for Kilawani First Site and Mamole to strong at Kilawani Kwa Joseph.
For Katangi,Kwa-Vonza Hill and Independent crusher sites Results of AIV show satisfactory results bordering weak.
The results exhibit closeness of results with regard to specific gravity and dry unit weight.
Classification tests show the gravel materials at Syokithumbi show Plasticity Index(PI) of medium plasticity levels ranging from 17% to 19%,California Bearing Ratio(CBR) varying from 20% to 62%,maximum dry densities of 1996kg/m^3 to 2067kg/m^3, particle sizes of 0.075mm to 10mm and Optimum Moisture Content(OMC) of 7.9% to 12.2%.
Based on the above ,the study recommends the sites are generally suitable for road pavement construction materials.

***KeyWords*: Aggregate Impact Value,Sodium Sulphate Solution,California Bearing Ratio,Loss Angeles Abrassion,Plasticity Index**

ACRONYMS:

LAA	Loss Angeles Abrasion
AIV	Aggregate Impact Value
SSS	Sodium Sulphate Solution
PSD	Particle size distribution
NMC	Natural moisture content
CBR	California Bearing Ratio
PI	Plasticity Index
EIA	Environmental Impact Assessment

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1.0 INTRODUCTION

1.1 Background to the problem

Mining is described as the extraction of valuable minerals as well as the removal of other of geological materials from the earth. Mining is an activity that has been carried out since the prehistoric times, where stone and other metals were extracted from the earth.Mining activities have to be profitable to the miner seeking to gain from the extract, and involves prospecting for the extracts, analysis of its profitability as well as the extraction and reclamation of the land. Stone as one of the valuable mineral extract has always been used since the beginning of civilization to make early tools and weapons (Hartmann and Howard L, 1992) Mining techniques are divided into two excavation types, which include surface mining and subsurface mining. In the current times, surface mining is more common. In relation to extraction of rocks, surface mining is employed, and a technique known as open pit mining is used. Surface mining began in the mid sixteen centuries, and has been continually employed throughout the world; although it is majorly employed in the North American continent, where today, surface mining is much more common, and produces, for example, 85% of minerals (excluding petroleum and natural gas) in the United States, including 98% of metallic ores (Hartmann, 2002). This technique is used when the deposits of the useful rock are found near the surface. The open pits that produce building materials and dimension stones are commonly referred to as quarries. Extraction of materials using this method involves the use of heavy equipment that moves the earth and other huge machines that extract the final product, which in itself results to negative effects to the surrounding environment through noise, dust, and vibrations that are as a result of the activity, where also in some cases additional logging of forests is done in the vicinities of the mines to create room for the storage of debris and soil excavated. Stone has always been used for building and decorations because of its resistance to weather and for its aesthetic appeal. For example, India's use of stone for construction purposes can be traced back to 3200 B.C. The country's many innumerable temples and ancient palaces have been carved out of locally available stone. One of the most famous buildings, the TajMahal at Agra, portrays a long age tradition of stone architecture in the country (UNESCO World Heritage Centre, n.d.). Stone being an important component in the construction of homes is often demanded in large quantities, especially in our country Kenya. The demand for quarried aggregates is enormous (George M. Ndegwa, Oguta B, Calvince O, 2003). Developmental activities in Kenya that involves the construction of homes, factories and schools among other developments underpin the necessity of quarrying as an activity in the country. The quarrying and aggregate production industry is therefore a major player in the important role of steering the nation's economy through the provision of essential building materials and providing employment opportunities. Housing demand in Kenya supports the fact that there is an enormous reliance on stone aggregates, and bearing in mind that the population growth is placed at 4.2% per annum, which accelerates urban migration gives a projection of an annual increase of housing units, which currently stands at 206,000 units annually (CAHF, 2012).

The quarries are undeniably of economic significance in enhancing infrastructure growth and closing the infrastructure deficit.

1.2 Stone Quarry Sites Locations and General Geology

- The stone quarry sites are all located at Yatta Plateau at or around Kwa Kilui area of Kiusyani.
- Yatta plateau is in Kitui Rural Sub-County has various mineral resources and rocks occurring at different parts within its borders.The most dominant rocks are the Basement Systems which particularly encompass the metamorphic rocks.
- The rocks were formed during the Precambrian era and are the oldest rocks in the region.

All these rock formations therefore fall in the Mozambican belt that runs from Northern parts of Kenya through Taita Taveta to Tanzania and Mozambique.

These rocks experience multiple dynamics of earth processes such as weathering,deposition,and aggressive metamorphism.

During the tertiary era,volcanism at the central parts of Kenya led to the eruption of lava and later there was flow and deposition of these materials.

This lava flow led to the formation of plains and plateau zones such as Yatta Plateau.Yatta Plateau is a geologic zone that is relatively flat and stretches several kilometres from Machakos County through the Western part of Kitui County to Tsavo East National Park.

This plateau has distinctive rocks and minerals that are stupendous from the other rocks in its environs.

The Yatta Plateau in Kitui County traverses the Yatta/Kwa Vonza Ward from Kwa Kilui area through Kanyangi Ward to Athi Ward and some parts of Ikutha.The rocks in this zone are known as phonolites and these are igneous extrusive rocks that are aphanitic to phophyritic in texture,compact and consist of nepheline and dominant potash feldspar minerals(feldspathoids).

Phonolite forms from magma with relatively low(under-saturated)silica content due to partial melting of highly aluminous rocks such as tonalite and metamorphic rocks.

Its hardness ranges from 5.5 to 6 in the Mohs hardness scale and breaks into thin,tough plates which make a ringing sound when struck by a hammer.

1.3 Extraction of phonolite rocks

Phonolites occur near the earth's surface and even other massive rocks have been exposed due to erosion.

Since these rocks are slightly rounded and massive,surface mining methods such as open pit mining can be applied to the extraction of these rocks using excavators.

Huge lumps of these rocks occur within the ground and thus,they need to be broken into smaller sizes for transportation.

Hammers and mallets can then be used to hit the rocks into smaller sizes for hardcore and ballast products.

Uses of phonolites:

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Crushed rock form gravel aggregates used as ballast for building construction and also finer grades are applied for tarmacking roads.
Phonolites are also cut into blocks for dimension stone used in building construction and fencing.
This is an essential rock in roofing when cutting into thin slabs and this is a substitute to slates.
Rare earth,phosphates,and uranium mineralization may also occur in phonolite formations.
Decorative stones may also be derived from phonolites for landscaping.
This area, particularly Kwa Kilui in Kiusyani,is currently the source of road construction materials for Kibwezi-Kitui-Mwingi-Isiolo-Ethiopia international trunk road(A9) construction which road is 508kilometres in length.
There are serious mining activities ongoing towards satisfying the demand for roads and building construction materials within Kitui County and beyond.
Extraction of stones is mainly by use of simple hand-held tools after which the materials are loaded into a waiting truck for transportation to their destinations.
Comprehensive details on the quarry sites,locations,distance from the proposed Ken Road project,ownership and excavation methods are presented on table 1 attached in this report.
This report mainly presents the findings of a quarry stone prospecting and laboratory testing exercise carried out at different locations in Kitui Rural Sub-County in Kitui County in the Republic of Kenya.
The purpose of the quarry prospecting and laboratory testing was to provide information pertaining to the suitability of the rock aggregates with regards to various parameters of viz; abrasion value,water absorption,soundness test,specific gravity and impact value.Other gravel tests for two separate quarries were Atterberg limits,particle size distribution,bulk density,California Bearing Ratio,unit weight and proctor tests.
The quarry stone prospecting involved several sites at varying distances from the proposed road construction site mainly in Kitui Rural Sub-County of Kitui County along Yatta Plateau. Sampling was done at every site with two samples recovered subsequently followed by Laboratory testing, engineering analysis and reporting.

1.4 Research questions
1. What are the physical properties of the rocks sampled?
2. What are the chemical and water absorption properties of the rocks sampled?
3. What are the mechanical properties of the rocks sampled?
4. Are the rocks suitable for road construction?

1.5 Objectives
1. To evaluate the rock physical properties
2. To assess the rock chemical and water absorption properties
3. To examine the mechanical properties of the rocks sampled?

1.6 Justification of the study Quarrying is an important part of economic development as it serves as the backbone of an exponentially growing industry in the housing sector. The study focuses on quarries for rock and their suitability for construction of a selected road in Kwa-Vonza /Yatta Ward in Kitui Rural Sub-County in Kitui County,Kenya.

1.7 Significance of the study
Quarrying has an impact both economically and socially, where it contributes to the County,National and global economy as an industry, and has created many job opportunities for many people.

1.8 Scope of the study
KenRoad select road is located at Yatta/Kwa Vonza ward and stretches from Nyumbani Village along KEFRI (Kenya Forest Research Institute) land to the turn off at Kenyatta University-Katutu road (E738).The quarry sites are however spread across Kwa-Vonza /Yatta Ward in Kitui Rural Sub-County spanning over 90 kilometres.
Kwa Vonza is located about 30 kilometers from Kitui town. It is in Yatta/Kwa Vonza ward, within Kitui Rural Sub County. Yatta/Kwa Vonza ward is approximately 757.4 kilometers sq. The ward shares its borders with four other wards and a county: Machakos county to the west, Mulango ward to the north east, Kanyangi ward to the south, Kisasi ward to the east, and Kwa Mutonga/ Kithumula wards to the north.
Kwa Vonza is located between two hills but the area has a low-lying topography. Apart from the slopes of the two hills, the general landscape is flat with a plain that gently rolls down towards the west. The other significant relief feature is the Yatta Plateau, which stretches from the north to the south of Kitui County. The plateau is characterized by plain wide shallow spaced valleys. Kwa Vonza has a semi-arid climate with two major rain seasons: short rains between October–January and long rains March–May. The short rains are more reliable than the characteristically unreliable long. The periods falling between June to September and January to March are usually dry. The annual rainfall ranges between 500–1050mm with 40 per cent reliability.The area experiences hot temperatures for the greater part of the year. The maximum mean annual temperature range between 26º C and 34º C. The minimum mean annual temperatures in the county vary between 14º C and 22º C. The land use of the Kwa Vonza is mainly characterised as range-bush land with subsistence agriculture but is currently transforming into urban land charaterised by the development of residential and commercial buildings, as well as urban infrastructure
The geology of the proposed road in Kwa Vonza consists of red sandy soils, loamy sand soils and patches of black cotton soils.The patches of the black cotton soil are limited at the intermediate portion of the road around coordinate -1.3262899,37.8219379. Finally, the necessary recommendations are going to be provided.

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3.0 METHODOLOGY

3.1 Research area

Yatta/Kwa Vonza ward is approximately 757.4 kilometers sq. The ward shares its borders with four other wards and a county: Machakos county to the west, Mulango ward to the north east, Kanyangi ward to the south, Kisasi ward to the east, and Kwa Mutonga/ Kithumula wards to the north.

The geology of the proposed road in Kwa Vonza consists of red sandy soils, loamy sand soils and patches of black cotton soils.The patches of the black cotton soil are limited at the intermediate portion of the road around coordinate -1.3262899,37.8219379.

Initial prospecting was through site visits to the stone quarry sites at in Kwa Vonza,Kiusyani at Kwa Kilui and Katangi for purposes of reconnaissance, identification,familiarization and appreciation of the overall environment and securing information to guide in the final siting.

This was followed by subsequentl visit of the to the various stone quarry sites for final mapping of the sites.

The quarrying and subsequent results are presented at the end of this study report.

The stone quarry samples in most quarries,mostly existing, were recovered manually and without use of explosives or mechanical plant.

All the samples were preserved in gunny bags for laboratory testing.The siting and sampling was based on the observed suitability and information existing at the time as to the sufficiency of the sampled sites with regard to quantities and quality of the stones.

4.0 RESULTS AND DISCUSSIONS

Recovered bulk samples in gunny bags clearly labelled were transported to the soil laboratories and subjected to testing in accordance with test procedures. The test methods and the results obtained were analysed and are presented in this report in Appendix 1.The identified quarries for stones generally have sufficient quantities for the proposed road works.

All quarry stones meet the requirements of water absorption which should be less than 2%.

All quarry stones meet the requirements of sodium sulphate solution threshold of less than 12%.

The dry unit weights and the specific gravity for the stone quarry sites are convergent and averaging at 2.0.

Aggregate Impact Value (AIV) results range from very strong for Kilawani First Site and Mamole to strong at Kilawani Kwa Joseph as shown in the appendices.For Katangi,SEKU Hill and Independent crusher sites Results of AIV show satisfactory results bordering weak.

The excavation is generally manual with no need for blasting.The results exhibit closeness of results with regard to specific gravity and dry unit weight.

The percentage LAA and AIV demonstrate significant variations especially for Katangi and SEKU Hill while SSS varies from 1.3 to 4.5 across the quarry samples with absorption variations of 0.94 to 1.4.

Classification tests show the gravel materials at Syokithumbi show PIs of medium plasticity levels ranging from 17% to 19%,CBRs varying from 20% to 62% remarkably higher than earlier test,maximum dry densities of 1996kg/m3 to 2067kg/m3, particle sizes of 0.075mm to 10mm similar to earlier test results, OMC of 7.9% to 12.2%.

Based on the above parameters for the gravel sites meet certain plasticity and other requirements.Stabilization will require reference to the design manual on the percentage of lime.

6.0 RECOMMENDATIONS

In light of the results of the stone quarry sample tests Kilawani Kwa Joseph,Mamole and Kilawani .

First sites are recommended for the proposed road in that they have the best results.

Save for Kwa-Vonza Hill Quarry site,the recommended sites are approximately the same distance as the others from the project site.

Kilawani Kwa Joseph has sufficient quantities that require manual methods using hand held tools and can be leased or the materials can be excavated by the owners for sale in the desired quantities.

Kilawani First site occasionally requires blasting and loosening by excavator and breaker.

Notably,the gravel sites have been used to improve the Kwa Vonza Katutu road E738.

Similarly,the Kibwezi -Kitui international trunk road(A9) is currently using crushed stone
aggregates from Kwa Kilui in Yatta Plateau which is the location Kilawani and Mamole quarry sites.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The report proposes the use of Pavement Design Guidelines for Low Volume Roads vis a vis Road Design Manual III and Road Design Manual Part I.

That the soils and rocks sampled are generally suityable for road pavement construction.

Environmental Impact Assessment Report is a pre requisite for both the project and the quarry site.

Stabilization of the soil at various chainages at suitable percentages as per design manual

Excavation and removal of all black cotton soil where encountered along the proposed road

Maximum compaction using vibratory rollers to 95% MDD

Adequate ditches for maximum drainage of flood/storm water

Establish adequate elevations,gradients and cambers of 3% along the road profile

Establish suitable inlet inverts for hydraulic structures including drifts and box/culverts

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APPENDIX I
SUMMARY TEST RESULTS

SUMMARY OF TEST RESULTS
(In accordance with BS 1377:1990/AASHTO T99/T180 & T193)

Site: FROM NYUMBANI VILLAGE TO E738 (KWA VONZA-KATUTU) JUNCTION

Sample No.	Grading: % Passing BS Sieve (Wet & Dry Sieve Analysis) (BS 1377:1990)											Plasticity (BS 1377:1990)					Compaction		NMC	BULK DENSITY	CBR TEST (AASHTO T193)	
	28 mm	20 mm	10 mm	5 mm	2 mm	1 mm	0.6 mm	0.425 mm	0.300 mm	0.150 mm	0.075 mm	LL %	PL %	P.I %	LS %	PM %	MDD Kg/m^3	OMC %	%	Kg/m^3	CBR@ 100% MDD 4 Days soak	
																					CBR%	Swell %
QUARRY1 SYOKITHUMBI PIT A,W	100	100	90.4	80.4	72.9	62.8	53.1	48.2	42.1	29.2	20.8	37	18	19	9	916	2015	12.2	2.9	2039	22	21
QUARRY1 SYOKITHUMBI PIT B,E	100	100	84.5	64.3	42.2	28.7	22.4	20.4	18.3	15.1	12.4	33	16	17	8	347	2067	9.9	2.6	2094	62	19
QUARRY2 SYOKITHUMBI PIT A,W	100	100	80.0	62.4	50.5	43.5	37.2	33.0	29.2	24.7	20.1	36	16	17	8	561	1996	11.2	1.2	2002	20	24
QUARRY2 SYOKITHUMBI PIT B,E	100	100	71.4	55.7	47.9	42.1	36.1	32.7	29.3	24.2	18.0	32	12	18	9	589	2070	7.9	1.6	2008	59	17

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SUMMARY OF TEST RESULTS

Site: *NYUMBANI VILLAGE TO E738 (KWA VONZA-KATUTU) JUNCTION*

SAMPLE	AIV %	DRY UNIT WEIGHT Kg/m^3	L.A.A %	SPECIFIC GRAVITY	SSS %	WATER ABSORPTION %
KATANGI SITE A,W	29	2.011	51	2.493	4.0	1.25
KATANGI SITE B,E	30	2.009	53	2.394	4.1	1.29
KILAWANI 1ST SITE NORTH (Kwa Mbuvi)	7	2.339	**16**	2.477	1.3	0.98
KILAWANI 1ST SITE SOUTH (Kwa Mbuvi)	7	2.350	**16**	2.484	1.4	0.96
KILAWANI QUARRY SITE NORTHERN (Kwa Joseph)	21	2.086	**27**	2.479	3.5	1.08
KILAWANIQUARRY SITE SOUTHERN (Kwa Joseph)	9	2.310	**15**	2.547	1.6	1.02
MAMOLE (KILAWANI) NORTH	8	2.273	**17**	2.492	1.9	0.94
MAMOLE (KILAWANI) SOUTH	8	2.254	**16**	2.467	1.8	0.98
SEKU HILL 1 100m NEAR RD	33	2.040	62	2.498	4.5	1.17
SEKU HILL 1 FAR END 200m	32	2.055	61	2.481	4.3	1.21
INDEPENDENT CRUSHER	32	1.98	50	2.0	4.0	1.3
INDEPENDENT CRUSHER	30	1.8	52	2.1	3.9	1.4

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APPENDIX II : DETAILED STONE QUARRY SITE INFORMATION

S/No.	STONE QUARRY SITE	LOCATIONAL CO-ORDINATES	DISTANCE FROM PROPOSED PROJECT	REMARKS
1.	**Syokithumbi** Quarry 1	S-1^{0}19'32.7'' E-37^{0}50'25.5''	Located within 3.3kilometres from Nyumbani KenRoad	Gravel Site with *murram* Existing gravel site earlier used for Kenyatta University-Katutu Road E738 Privately owned and available Quantities sufficient
2.	**Syokithumbi** Quarry 2	S-1^{0}18'34.6'' E-37^{0}49'56''	Located within 3.3kilometres from Nyumbani KenRoad	Gravel site with *murram* Existing gravel site earlier used for Kenyatta University Katutu Road E738 Privately owned and available Quantities sufficient
3.	**SEKU-KV** Quarry Site	S-1^{0}19'4.5'' E- 37^{0}45'30.5''	10Kilometres and at the foot of Kwa Vonza Hill	Expansive exposed and rock strata excavatable by use of hand tools and excavator where necessary to loosen the rocks. Public land vested in the Local Authority. Quantities sufficient
4.	**Mamole** Quarry Site	S-1^{0}29'24.9'' E-37^{0}48'12''	Approx. 36kilometres	Expansive exposed and deep rock strata excavatable by use of hand tools and excavator where necessary to loosen the rocks. Existing quarry privately owned and can be leased. Quantities sufficient
5.	**Kilawani** Kwa Joseph	S-1^{0}30'9.7''	Approx. 41 kilometres	

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		E-37^{0}47’58’’		Expansive exposed and deep rock strata excavatable by use of hand tools and excavator where necessary to loosen the rocks. Privately owned existing quarry and can be leased. No blasting required Quantities sufficient
6.	**Kilawani First Site** Kwa Mbuvi	S-1^{0}29’34.6’’ E-37^{0}48’26.9’’	Approx. 40kilometres	Expansive exposed rocks excavatable by use of excavator and breaker. Certain portions may require blasting. Privately owned existing quarry Own source of materials and crusher for aggregates Quantities sufficient
7.	**Katangi** Quarry Site	S-1^{0}24’59’’ E-37^{0}43’51’’	34Kilometres along the road from Kwa Vonza to Machakos through Kyua	Rocky outcrops adjacent to road. Blasting NOT permitted. Existing Quarry Quantities sufficient
8.	**Independent crusher** Kwa Kelvin	S-1^{0}30’40’’ E-37^{0}40’58’’	42kilometres at Kilawani	Crushes coarse aggregates mainly 20mm-25mm sizes and resultant quarry dust Operational and privately owned NO own source of quarry stones.Sourced from neighbourhood. Quantities depend on other quarries
9.	**County Crusher**		48kilometres at Kwa Kilui	Not Operational

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APPENDIX III

Rainfall Frequency Annexes for the proposed project construction site

Rainfall frequency analysis is an important component in the estimation of peak flows for specific return periods, especially where there are no stream flow records. A basic assumption is made that the return period for a storm corresponds to the return period for flows. Furthermore, the duration of the storm should correspond to the time of concentration of the catchment (tc). The Rainfall Frequency Atlas of Kenya (Ministry of Water Development, 1978) provides rainfall duration-frequency (RDF) maps for the whole of Kenya for different combinations of storm duration and return periods as shown below. These maps are essential where the time of concentration is significantly less than 24 hours, which is the case for small catchments.

MAPS

- Annual Rainfall;
- Annual Potential Evapotranspiration (PET);
- 50 Year Rainfall Intensity 12 Hour Storm;
- 100 Year Rainfall Intensity 12 Hour Storm;

Note: Additional rainfall intensity maps are available on the web site.

Return Period	Storm Duration							
5 years	10 min	30 min	1 hour	2 hour	3 hour	6 hour	12 hour	24 hour
10 years	10 min	30 min	1 hour	2 hour	3 hour	6 hour	12 hour	24 hour
25 years	10 min	30 min	1 hour	2 hour	3 hour	6 hour	12 hour	24 hour
50 years	10 min	30 min	1 hour	2 hour	3 hour	6 hour	12 hour	24 hour
100 years	10 min	30 min	1 hour	2 hour	3 hour	6 hour	12 hour	24 hour

Larger format maps can be printed by downloading from the Website or CD and printing as required.

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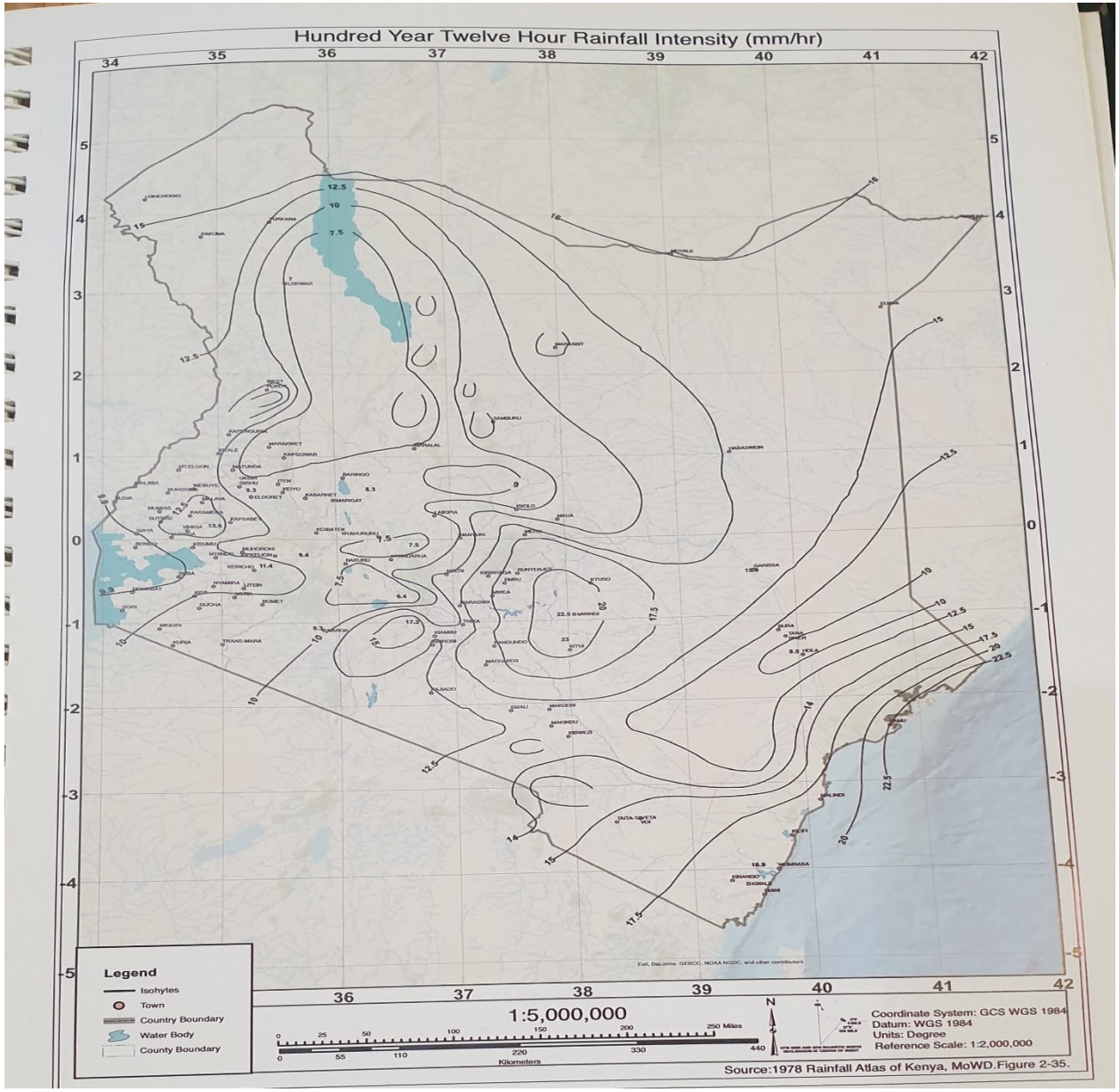

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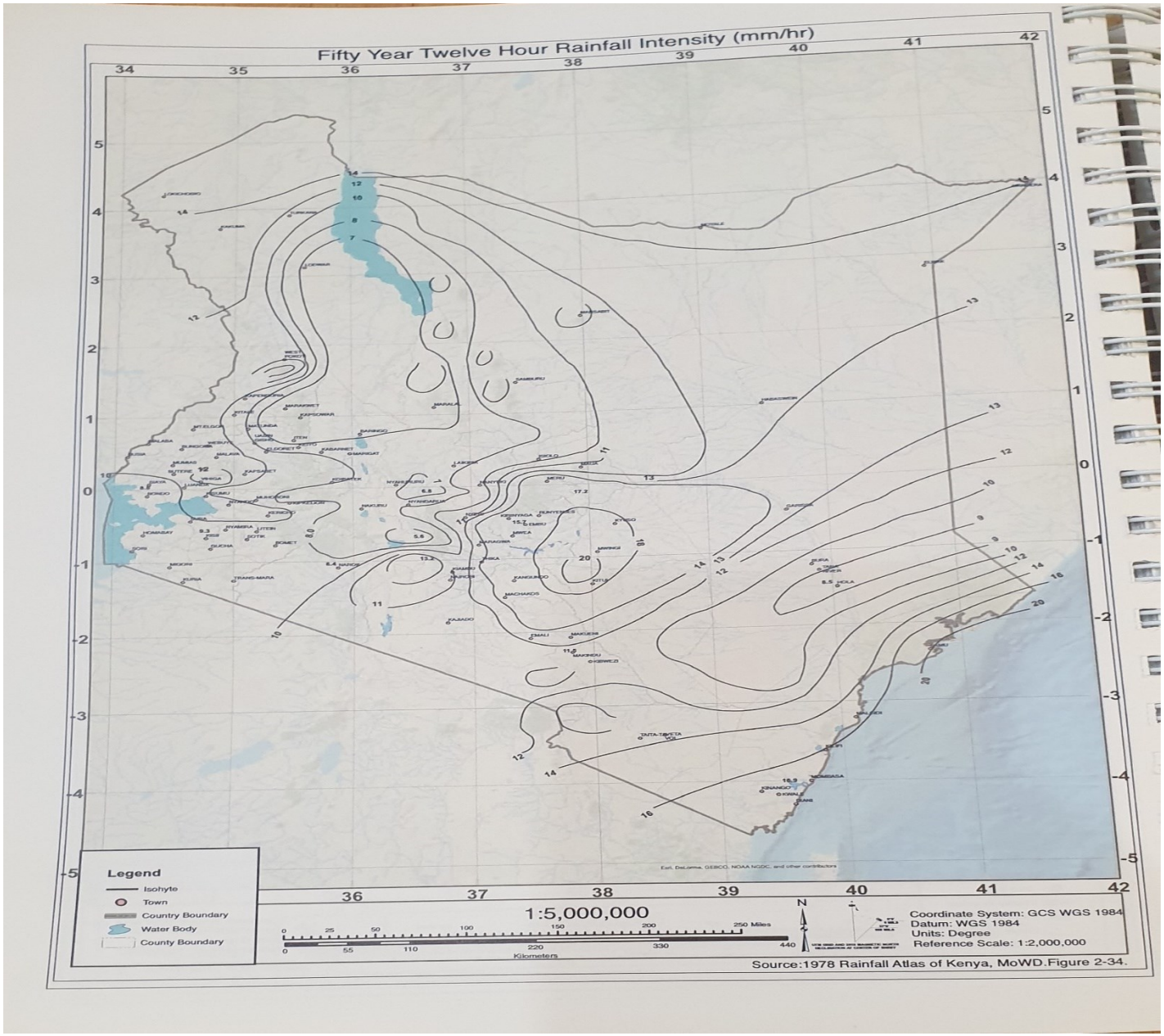

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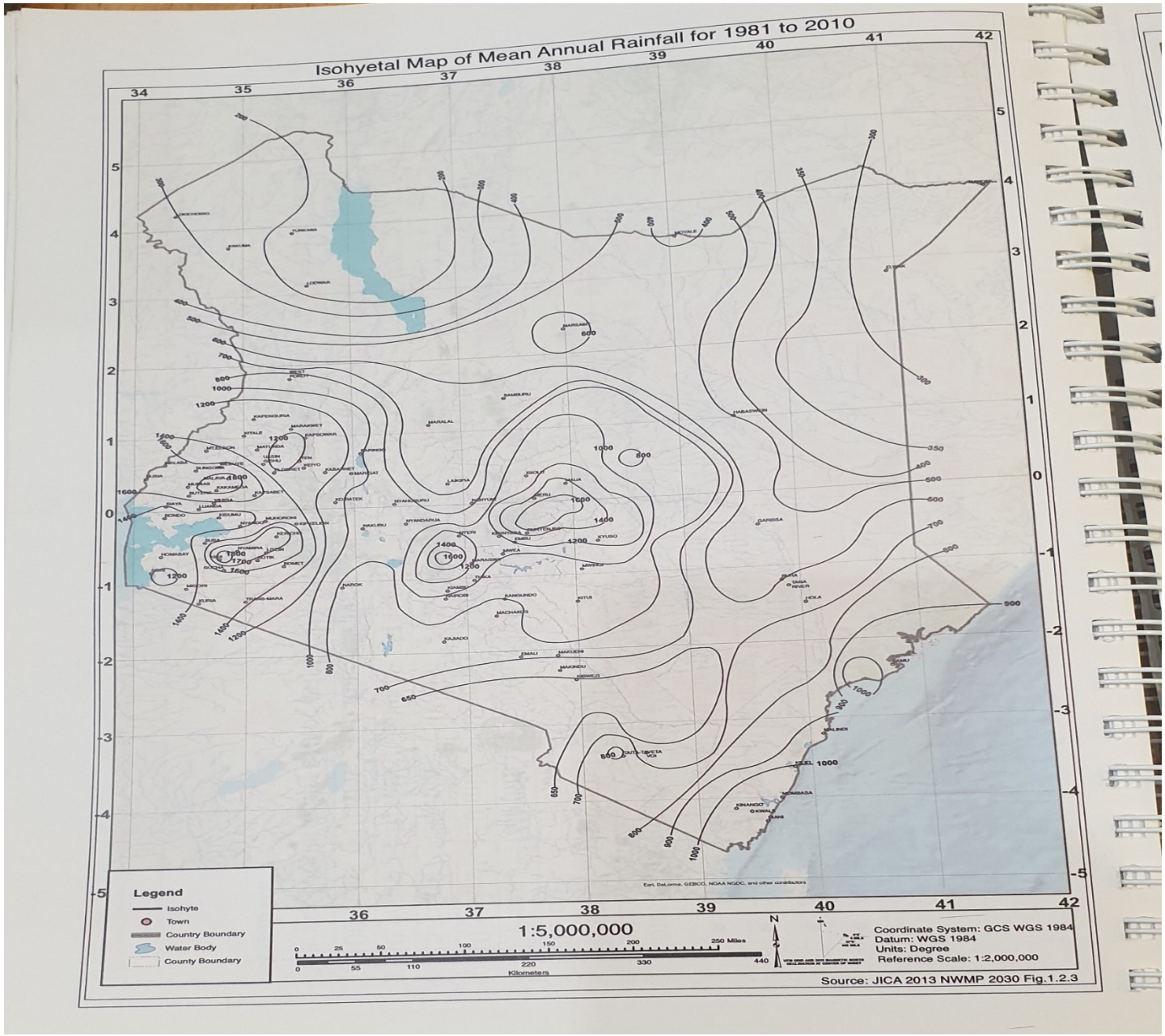

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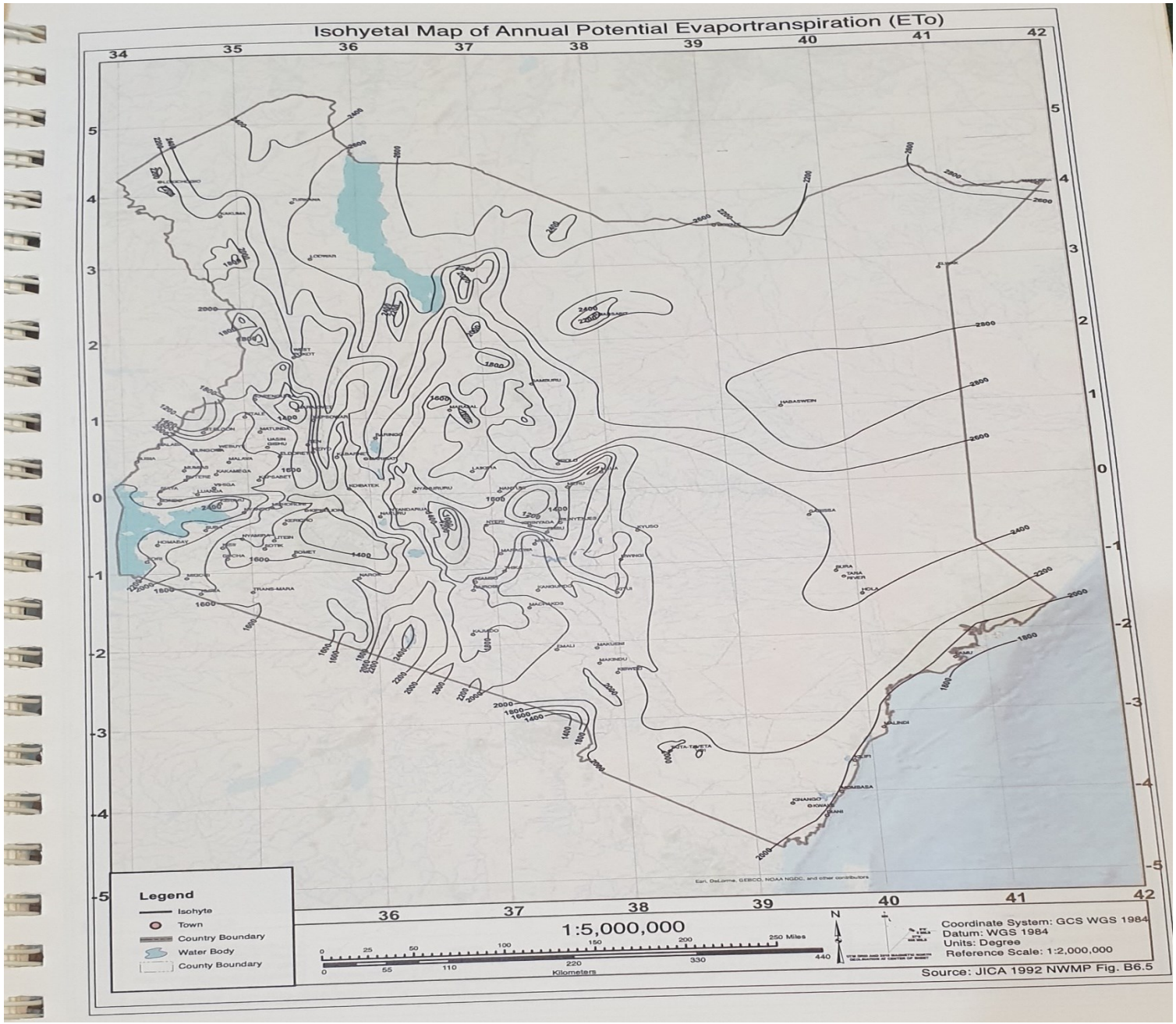

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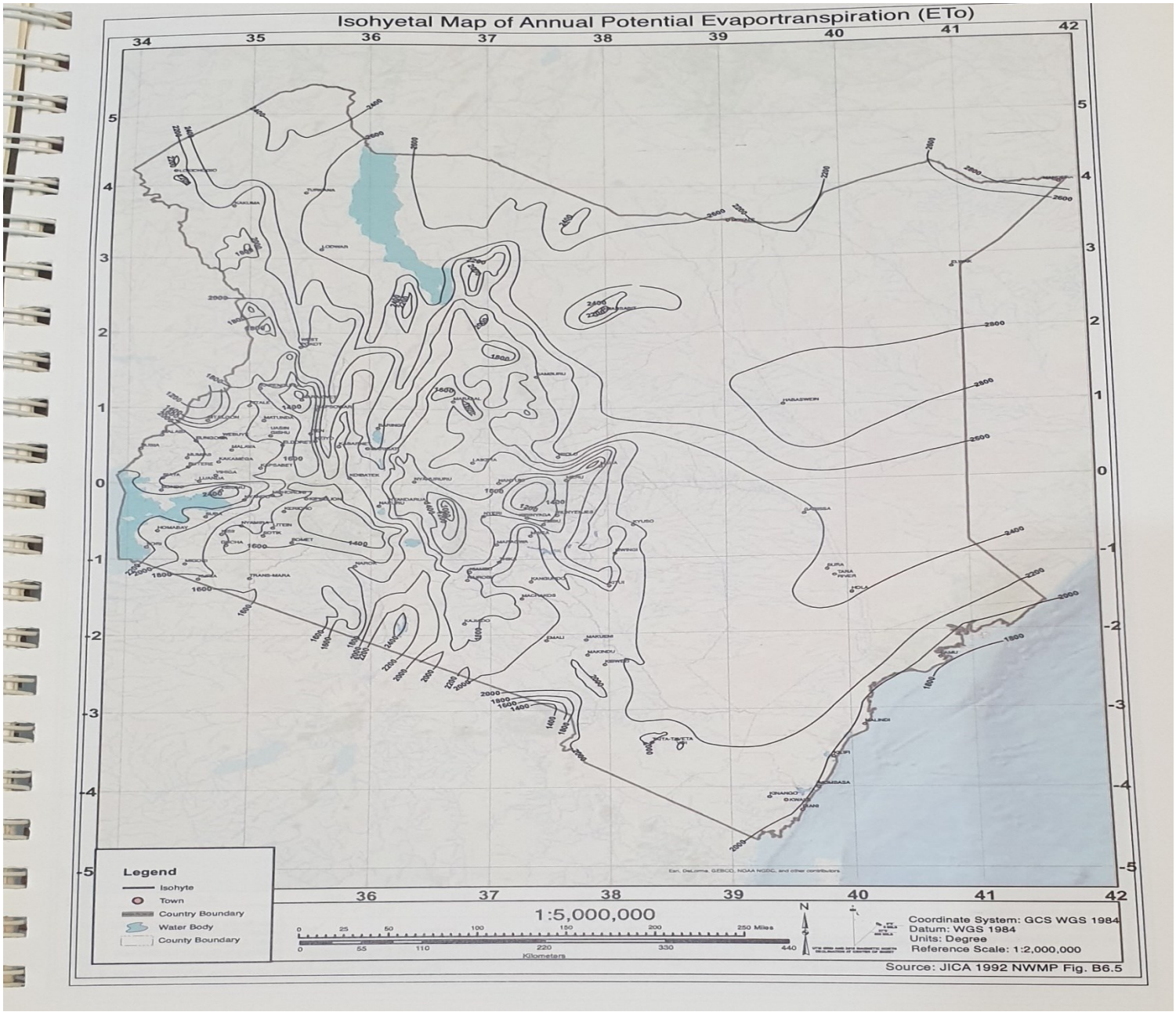

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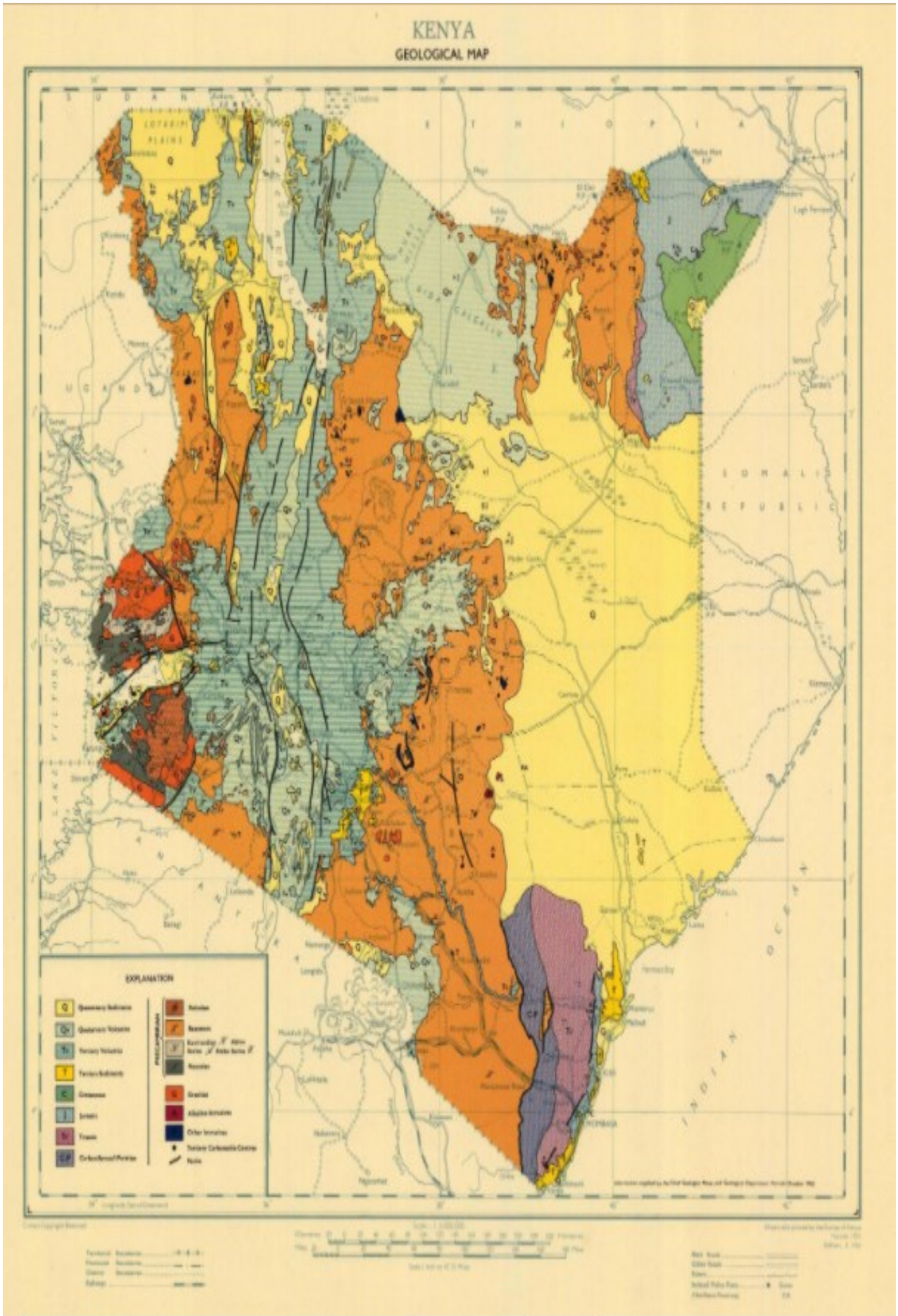

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https://esdac.jrc.ec.europa.eu/images/Eudasm/Africa/images/maps/download/afr_keg.jpg （Geological Map of Kenya）

APPENDIX IV
Site Photos

SEKU KV Quarry Site

SEKU KV Quarry Site

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SEKU KV Quarry Site

Kilawani Quarry Site Kwa Joseph

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Kilawani Quarry Site Kwa Joseph

Kilawani First Site Kwa Mbuvi

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Kilawani First Site Kwa Mbuvi

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Kilawani First Site Kwa Mbuvi

Independent Crusher

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Mamole Quarry Site

Katangi Site

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Syokithumbi Quarry Site 1

Syokithumbi Quarry Site 1

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Syokithumbi Quarry Site 2

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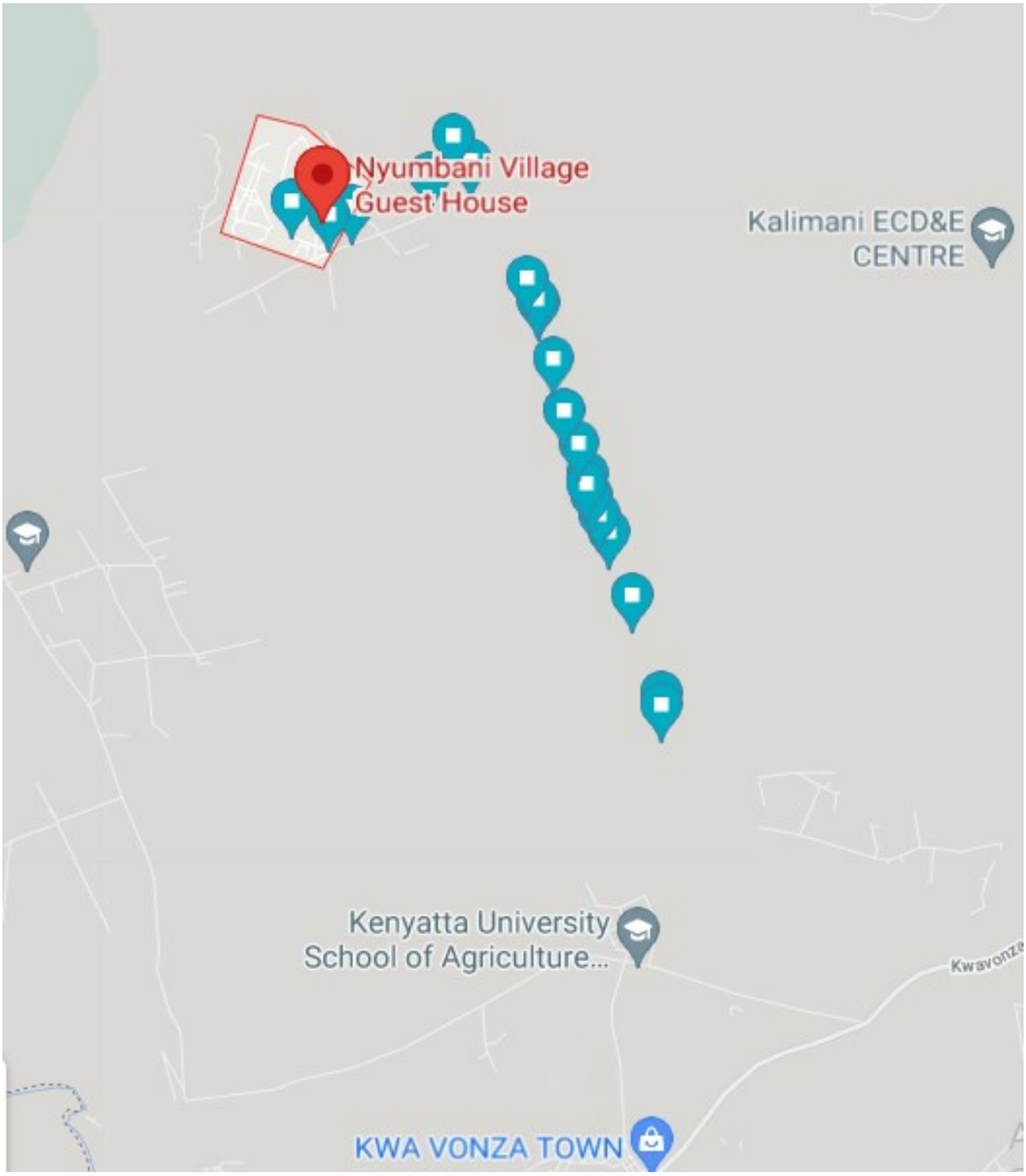
APPENDIX V

Select Proposed Site Area



Project Area Map