

CTCN-UNIDO EAST AFRICA GEOTHERMAL TECHNICAL ASSISTANCE
GEOTHERMAL RESOURCE ASSESSMENT SITE SELECTION GUIDELINES

1. Site Selection Approach and Methodology

The site selection methodology is presented in Figure 1.1. As an initial step, primary source documents (feasibility studies, technical reports etc.) should be obtained for the country/region/study area and where applicable, additional publicly available information should be gathered through supplemental research. The data generally includes reports and studies of geothermal resources at various stages of development – from pre-feasibility through more advanced stages (e.g., operation). In most cases, the data that has been generated comes from high enthalpy sites utilized for power generation, rather than for direct use applications. Therefore, gaps in the data should be identified for each site while taking into account the best practices that are applied in geothermal exploration. To account for these data gaps and utilize the existing data, a broader assessment should be undertaken, such as including cascading systems (in cascading systems, the effluent from a power plant can feed a direct use application before it is reinjected or disposed of). **Figure 1.1** shows the steps that can be followed in the data analysis and site selection, whereby a two-phased assessment is followed to identify a selected number of target resources (in this case, the top three resources were identified).

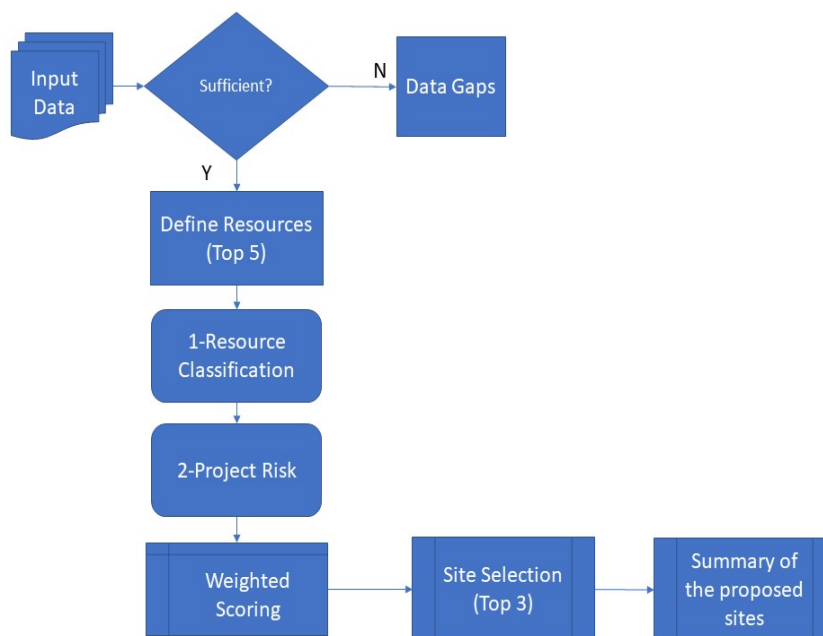


Figure 1.1: Site Selection Methodology

In the first phase of the assessment, existing/available data in each site should be used to classify the site. The classification system has been developed from international geothermal classification systems and ranges from the lowest confidence level – an inferred resource – to the highest confidence level – a proven reserve – dividing the resources into five categories (**Figure 1.2**). A total of 56 criteria were used to classify each site. Each data point was then assigned a “1” or a “0” according to its existence in the data-set, with the sum of the given values used to determine a specific category for each site.

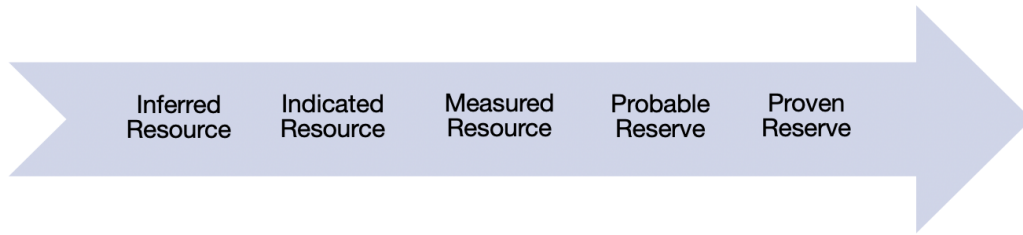


Figure 1.2: Resource Classification

The second phase involves the project development status assessment/project risk which included 33 criteria that were developed using the ESMAP’s Project Risk graphic. The scoring weights were identified accordingly. In the weighted scoring system presented here, projects in their initial stages of development were assigned lower values (1-5), whereas projects in more advanced stages of development and moving towards construction and operation were assigned increasingly higher values (5+) (**Figure 1.3**). Thus, the total weighted score of a given project closely aligns with its level of development – the higher the overall score, the more preferred the geothermal site.

The resource classification and project development status assessment together provide a detailed understanding of the geothermal sites/resources in each region. This two-phased approach was utilized to analyze and compare sites and ultimately to select the top three sites. These sites generally include a combination of the most advanced and developed project(s) in the region along with additional promising resources, focusing on low-to-medium temperature resources where applicable, and/or projects considered to be technically and financially viable with reduced project development risk.

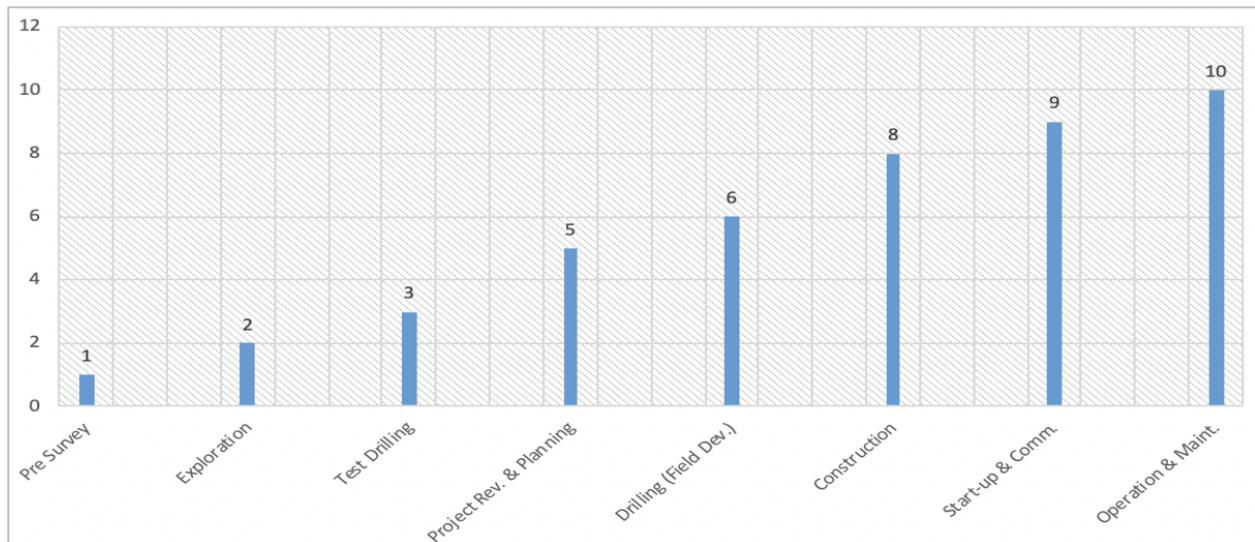


Figure 1.3: Project Status and Corresponding Weights Assigned

2. Site Selection Guidelines

Below is a list of tasks and tools that can be used to conduct site selection using the given methodology.

TASKS	GUIDELINES	RELATED TOOLS TO BE USED
1. COMPILING DATA	Data acquisition, compiling for the region/sites	Annexes 1 and 2 provide information on how to approach data compilation
2. FILL IN DATA GAPS	Review best practices for data inputs; if appropriate collect data through available sources or conduct new surveys	Annex 3 describes best practices that are widely accepted by the International Geothermal Association (IGA)
3. INITIAL FOCUS AREA	From the data collected, a regional or project-based focus can be developed	Available data and expert knowledge can focus on a specific site/region for development
4. RESOURCE CLASSIFICATION	Defined criteria from this work can be utilized for any site - 1st phase analysis	Annex 4 lists the criteria to define the resource classification
5. PROJECT RISK ASSESSMENT	Defined weighted scoring can be utilized for any site - 2nd phase analysis	Annex 5 lists the criteria and weight assigned for project risk status
6. SITE RANKING AND SELECTION	Total score of each site will be used to categorize and rank the sites	Annex 6 provides an example from this study for different sites and their scores

ANNEX 1: DATA COLLECTION APPROACH/GUIDELINES

The guidelines below summarize the steps taken to review existing low-to-medium temperature geothermal systems to identify gaps in data and information and select/validate the suitable sites.

Task	Guidelines
Collection of relevant documents and reports	<p>Deliverable: Please compile the latest and most relevant data related to geothermal direct use in the country. The documents/reports should cover geothermal direct use applications in local industries such as agriculture (with a special focus on fish farming), agricultural-processing, manufacturing and tourism among others. Please list your findings in the enclosed Excel Spreadsheet, where you can prioritize the results based on the quality of the data, its relevance, recency, resource identification (if applicable).</p> <p>Sources of data:</p> <ul style="list-style-type: none"> - NDE/Project Proponents - Public Officials: local government officials and/or institutions (Ministry/Dept. of Energy, Geology, Water, Agriculture, Mining, Land etc.) - Published reports/academia: UNEP African Rift Geothermal Development Facility (ARGeo) reports (among others)
Geothermal sector over- view and country maps	<p>Geothermal Overview: Brief description of the contribution of geothermal (if applicable) to power generation and/or direct uses in the country. Over- view of the geothermal resource available as well as a description of projects currently in the pipeline, under development or projects that are already online.</p> <p>Deliverable:</p> <p>(i) Brief (1-page) summary overview of geothermal sector (focus on direct use)</p> <p>(ii) Country-scale maps that illustrate the following:</p> <ul style="list-style-type: none"> - Current geothermal direct use applications - Potential sites for future direct use applications - Geothermal resource maps (temperatures) - Geology (e.g., hydrothermal alteration), geophysics (e.g., heat flux, gravity, electromagnetic surveys), geochemistry maps (e.g., hot springs) - Drilled wells (oil, water or geothermal well data) <p>Sources of data:</p> <ul style="list-style-type: none"> - NDE/Project Proponents - Public Officials: local government officials and/or institutions (Ministry/Dept. of Energy, Geology, Water, Agriculture, Mining, Land etc.) - Published reports/academia: UNEP African Rift Geothermal Development Facility (ARGeo) reports (among others); local universities and institutes also produce country-specific data that may be available in journals or conference proceedings/meetings - Geothermal Industry Associations: E.g., Geology/Geophysical Engineering Associations may have data available on country-scale geo- thermal maps

<p>Technical / Economic Data</p>	<p><u>Reports on various projects/sites as well as their technical and economic data:</u></p> <p>In order to select and validate the sites, more detailed data is required, including the following:</p> <ul style="list-style-type: none"> - Current Use (commercial? private?) - Neighboring resources (cascading system from a power plant?) - Background data (geology, geophysics, geochemistry reports) - Production and re-injection well data (with temperatures, pressure, flow rates, brine chemistry, depth, and well logs) - Short-term well testing results (e.g., pressure drop, water loss) - Long-term well testing results (interference testing between wells or projects) - Conceptual model (combined theory of the resource reasoning, 2D and 3D models (Leapfrog, Petrel software outputs) - Volumetric assessment (P90, P10 results) - Dynamic model if it exists (using Tough2, Tetrad reservoir estimation studies) <p><u>Sources of data:</u></p> <ul style="list-style-type: none"> - Geothermal Direct Use Feasibility Studies: especially a study with a “volumetric assessment” completed - Pre-feasibility studies: Monte Carlo Simulation - African Development Bank: “Bank Feasibility” Reports undertaken by private banks. This typically provides the best technical and economic data on the geothermal resource/demand (although these can be difficult to obtain due to confidentiality issues etc.) - Other: E.g., case studies undertaken by local geothermal sector authorities or institutions
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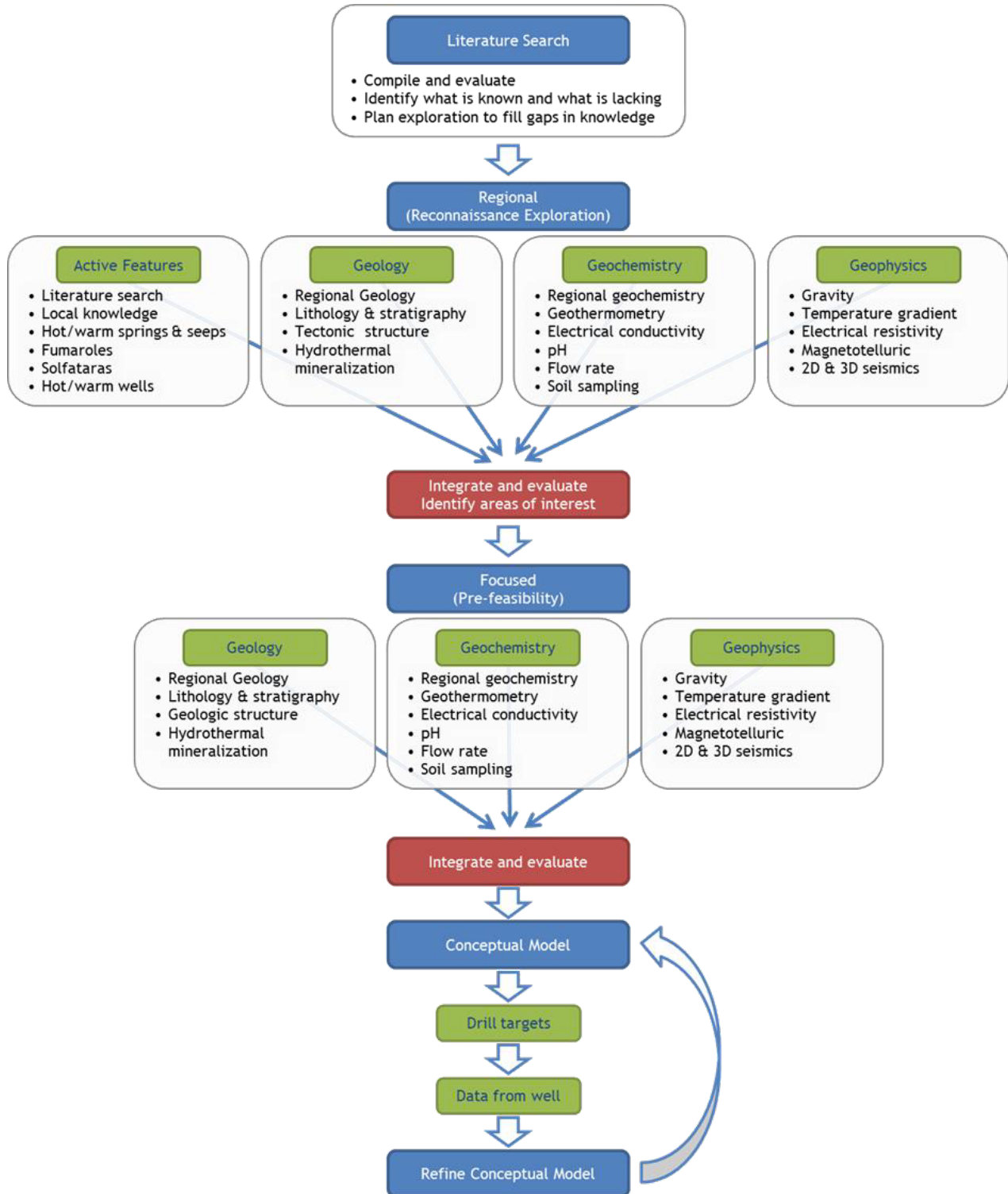
ANNEX 2: DATA COLLECTION - METADATA FORMAT

The following table can be used to organize relevant sources of data.

No.	<i>Report Name</i>	<i>Date of publication</i>	<i>Location</i>	<i>Resource Name</i>	<i>Neighboring Geothermal Sites (Resources and Reserves)</i>	<i>Data Quality Ranking</i>	<i>Resource Identification</i>	<i>Reference</i>
1						1	Low (?)	
2						2	Best (?)	
3						3	High (?)	
4						4	...	
5						5	...	

ANNEX 3: GEOTHERMAL EXPLORATION BEST PRACTICES

This figure illustrates best practices that are generally applied to geothermal resource exploration and development (Geothermal Exploration Best Practices, IGA, 2013).



ANNEX 4: SITE SELECTION – FIRST PHASE: RESOURCE CLASSIFICATION

This table shows the compiled resource classification system that can be applied to any project. There are a total of 56 criteria analyzed (assigned “1” if the data point exists and “0” if it does not exist). The classification goes from an Inferred Resource on the low end up to a Proven Reserve on the high end.

A) Inferred Resource; B) Indicated Resource; C) Measured Resource; D) Probable Reserve; E) Proven Reserve

	EXAMPLE		New Defined Criteria	0/1
A) Volume	Area	1	Surface manifestations	1
		2	Geothermal Gradient	1
		3	Geological analogy	1
		4	Geophysical mapping	1
		5	Estimated resource depth	1
Deliverability	Fluid T	6	Geothermometry	1
		7	Offset Wells Data	1
Cut off T		8	Min T for commercial operation	1
Permeability and P		9	Shallow well/ spring P and T	1
		10	Fault/ Aquifer permeability	1
Chemistry		11	No fluid acidity, uncontrollable solids deposition	1
	Hydrochemistry	12	Fluid flow estimated	1
Recoverability	Porosity	13	Rock Type (litho-stratigraphic)	1
B) Volume	Area	14	Geophysics surveys	1
		15	Shallow T gradients	1
		16	Surface heat flow	1
		17	Adjacent proven area	1
	Depth	18	Depth from geophysics / adjacent wells	1
Deliverability	Fluid T	19	Conceptual Hydrological Model	1
Cut off T		20	Estimated Reservoir Character (T°C)	1
Base T		21	Lowest T	1

Permeability and P		22	Well Liquid Pressures (adjacent)	1
		23	Extension of faults /aquifer permeability	1
Chemistry		24	Safe adjacent reservoirs (acidity etc.)	1
	Hydrochemistry	25	Fluid flow estimated	1
Recoverability	Porosity	26	Rock Type (litho-stratigraphic)	1
C) Volume	Area	27	Measured well Tmax	1
	Depth	28	Maximum well depth	1
Deliverability	Fluid T	29	Measured T / discharge enthalpy	1
Cut off T		30	Measured Reservoir Character (T°C)	1
Permeability and P		31	Measured discharge flows	1
Chemistry		32	Safe well discharge (acidity etc.)	1
	Hydrochemistry	33	Fluid flow measured	1
Recoverability	Porosity	34	Core porosity, reservoir transient behavior	1
D) Volume	Area	35	Geophysics surveys	1
		36	T gradients - surface heat flow	1
		37	proven adjacent reserves	1
	Depth	38	Depth from geophysics / adjacent wells	1
		39	Maximum depth target and reasonable drainage	1
Deliverability	Fluid T	40	Conceptual Hydrological Model from measured well data	1
Cut off T		41	Estimate from reservoir character	1
Base T		42	Lowest T	1
Permeability and P		43	Inferred extension of faults / aquifer permeability	1
		44	Well pressures (liquid) (adjacent proven or shallow wells data)	1
Chemistry		45	Safe drilled wells and safe adjacent reservoirs/ wells (acidity etc.)	1
	Hydrochemistry	46	Fluid flow and direction measured	1

Recoverability	Porosity	47	Inferred rock type from mapping and litho-stratigraphic interpretation	1
E) Volume	Area	48	Well T and Depth and well spacing defined	1
	Depth	49	Max depth drilled with drainage spacing	1
Deliverability	Fluid T	50	Well T measured or discharge enthalpy known	1

ANNEX 5: SITE SELECTION – SECOND PHASE: PROJECT DEVELOPMENT/RISK ASSESSMENT

This table shows the project status items and the corresponding weights and scores assigned to each.

	Project Risk		Scoring	Risk	Risk
	<i>Milestones</i>	<i>Description</i>	0/1	<i>Weight</i>	<i>Weighted Score</i>
1	Preliminary Survey	Data Collection	1	1	1
		Nationwide Survey	1	1	1
		Selection of Promising Areas	1	1	1
		Necessary Permits &EIA	1	1	1
		Planning of Exploration	1	1	1
2	Exploration	Geological	1	2	2
		Geophysical	1	2	2
		Geochemical	1	2	2
		Soundings TEM/ MT	1	2	2
		Gradient & Slimholes	1	2	2
		Seismic Data Acquisition	1	2	2
		Pre-feasibility Study	1	2	2
3	Test Drilling	Slimholes	1	3	3
		Full Size Wells	1	3	3
		Well Testing and Simulation	1	3	3
		Interference Tests	1	3	3
		First Reservoir Simulation	1	3	3
4	Project Review & Planning	Evaluation & Decision Making	1	5	5
		Feasibility Study & Final EIA	1	5	5
		Drilling Plan	1	5	5
		Design of Facilities	1	5	5
		Financial Closure	1	5	5

5	Field Development	Production wells	1	6	6
		Reinjection wells	1	6	6
		Cooling water wells(?)	1	6	6
		Well stimulation	1	6	6
		Reservoir simulation	1	6	6
6	Construction	Steam/ Hot water pipelines	1	8	8
		Direct Use Technology Design	1	8	8
		Substation & Transmission	1	8	8
7	Start-up & Commissioning		1	9	9
8	Operation & Maintenance		1	10	10
Total Maximum Weighted Score					132

ANNEX 6: SITE RANKING AND SELECTION

This table provides an example of the ranking process and how it can be used to select geothermal sites for direct use project development.

No.	Country	Resource	Classification	Class. Score (max 56)	Project Risk Score (max 132)	Total Score	Country Total
1	Kenya						
	1	Olkaria 1&2	Proven Reserve	56	126	182	
	2	Eburru	Proven Reserve	46	106	152	
	3	Menengai		53	105	158	492
2	Ethiopia						
	1	Aluto-Langano	Proven Reserve	44	106	150	
	2	Dubti	Proven Reserve	44	38	82	
	3	Abaya	Indicated Resource	22	20	42	274
3	Djibouti						
	1	Ambado- PK20	Probable Reserve	41	18	59	
	2	Asal Fiale	Probable Reserve	38	55	93	
	3	Hanle - Garabayiss	Indicated Resource	28	25	53	205
4	Tanzania						
	1	Kiejo Mbaka	Indicated Resource	20	22	42	42
5	Rwanda						
	1	Bugarama- Mashyuma	Inferred Resource	15	16	31	
	2	Gisenyi- Kilwa	Inferred Resource	14	15	29	
	3	Karago	Inferred Resource	10	9	19	79
6	Uganda						
	1	Kibiro	Indicated Resource	11	17	28	
	2	Buranga	Indicated Resource	10	15	25	
	3	Panyimur	Inferred Resource	10	15	25	78