GEOTHERMAL WELL SITING USING GIS: A CASE STUDY OF MENENGAI GEOTHERMAL PROSPECT

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ABSTRACT

Geothermal well site selection requires consideration of a comprehensive set of factors and balancing of multiple objectives in determining the suitability of a particular area for geothermal exploration drilling. The selection of geothermal well sites involves a complex array of critical multi-disciplinary factors and characterization. Geographic Information System (GIS), forms an invaluable link of field sample datasets from geologists, geophysicists, geochemists, reservoir scientists, and environmentalist. Geothermal spatial decision making could benefit from more systematic methods for handling multi- criteria problems while considering the physical and technical suitability conditions. Traditional decision support techniques lack the ability to simultaneously take into account these aspects which are achievable through geoprocessing and model builder tools in ArcGIS. GIS is the most efficient and effective modern technology used to make spatial multi criteria decisions that target potential geothermal resources. Comprehensive geo-scientific surface exploration was done in Menengai geothermal field prospect and multi-disciplinary data acquired through different spatial sampling techniques. The geo-scientific data from surface investigations was categorized into four key datasets; Geological (eruption centers, volcanic rocks, craters and faults), Geochemistry (soil gas, hot springs and acidic hydrothermal alteration zone), Geophysical (MT and TEM anomalies) and Surface heat loss (Heat loss anomalies). GIS was used to carry out spatial auto correlation of all the datasets, generation of trend surfaces and integrating and weighting all the four key datasets in a suitability model for geothermal well sites selection in Menengai prospect. Geoprocessing and Model builder tools were used for developing the suitabilitymodel and characterization. From the suitability model eight (8) geothermal well sites were eventually selected for exploratory drilling.

INTRODUCTION

Surface geothermal exploration projects entails in part identifying, analyzing and mapping of geothermal manifestations, such as fumaroles, altered grounds, and hot springs and other scientific survey techniques to determine prospective geothermal resources.For informed decision to be made there is need to combine and analyze the results from multi professional sample survey data and studies. Menengai area in the central rift was targeted for the accelerated development of geothermal resource. Surface geo-scientific measurements and data collection was done in order to determine the best area for drilling for subsequent reservoir assessment. The cost of drilling a typical geothermal well could range from KShs 400 Million to KShs 600 Million. Selecting suitable location for drilling a geothermal well will always remain a critical and a major decision by resource managers. The decision-making process need to combine and analyze the results of a number of different surveys and studies. GIS can be a powerful tool for minimizing human errors in identifying prospective areasfor drilling.ArcMap was used to develop a GIS Model for geothermal well drill site consisting of geoprocessing tools and a modelbuilder. Potential drill sites were defined and prioritized by assigning a weighted overlying selection query for geological, geophysical, geochemical, and heat loss data layers. GISwas used as an effective tool for the integral interpretation of geo-scientific data to determine best sites by combining various digital data layers.

Tabulated below is sample input data that was used from various surface measurements and studies in order to determine the best site location for a geothermal well:-

Data Type	**Derived Parameter**
Geophysics Dataset	
MT Anomaly	Heat source, reservoir extent
TEM Anomaly	Reservoir extent, permeability
Bouguer Gravity anomaly	Heat Source, Intrusive bodies
Geology Dataset	
Eruption Centers:	Heat Source
Structural setting:	Vertical Permeability
Petrological analysis	Geothermal Fluids/perm abilities
Geochemistry Dataset	
Soil gas (CO_2, Radon)	Leakages, Heat source
Fluids Chemistry	Recharge, permeability
Reservoir Science	
Convective & Conductive Heat Loss	Heat Source & quantity
Boreholes Temperature Data	Reservoir Temperature
Others	
Civil dataset	Access, source of bulk construction materials
Environment dataset	Environmental Impacts

METHODOLOGY

GIS was used for integrated data modeling for selecting best area for geothermal well sites for Menengai prospect area. Spatial Analysis, a process that examines the locations, attributes and relationships of features in spatial data was run to produce various spatial models, such as suitability models, from which new information useful for geothermal resource development is derived. GIS is used to carry out a various geo-processes and analysissince it is designed to handle large amounts of data and information. In addition, it is used forvisualization of geo-scientific survey results that enhance sound decision making and allows the effective management of the data.

The model builder tools in ArcGIS were used as a graphical environment in which to develop a multi-step diagram of the complex geoprocessing tasks. When the model is run, the Model builder processes the input data in the specified order and generates output data layers.

Figure 1 displays a workflow process diagram of various data input for identification of the most suitable location of geothermal well sites in Menengai prospect. The data selection is dependent on the discipline expert and criterion selected is based on other interpretations. For instance, the considerations that areas with CO_2 leakages of > 3.5% of soil gas as 'geochemical suitable areas' is based on the exploration Geochemist evaluation of the whole field data. Similarly the selection areas bound by Menengai caldera collapse as a geological suitable area is based upon the exploration Geologist's consideration of possible proximity to shallow hot magmatic bodies. Figure 1 below show the schema for selected parameters used for the suitability model.

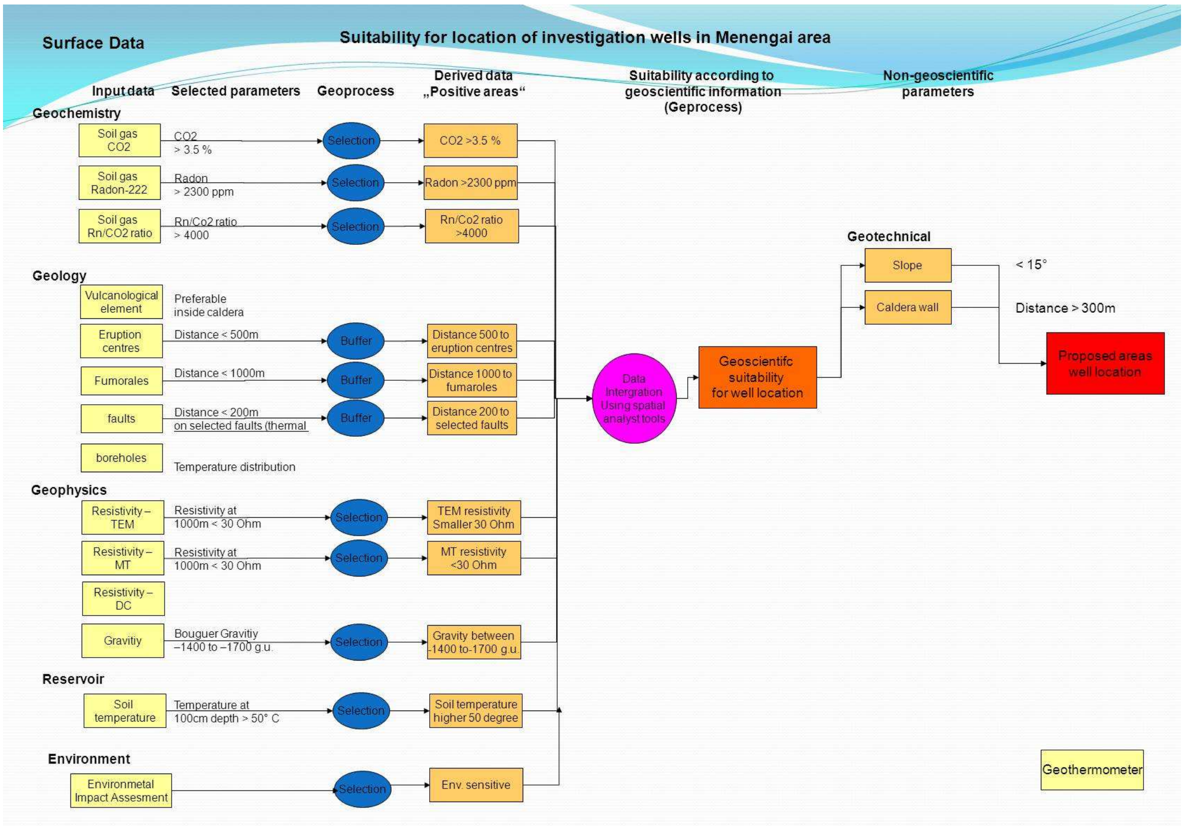


Figure 1: Workflow diagram: Data processing schema

GEOPROCESSED DATA LAYERS

Geothermal well site identification was carried out by using available digital datasets including reservoir science, geology, geochemistry and geophysics.Spatial analyst tools in ArcMap were used to derive ‘positive’ areas from all the scientific disciplines. Derivation of intermediate suitable areas requires creation of a geoprocessing model in ArcGIS model builder tool. The intermediate products are then integrated into a single suitability map. Data integration involves use of analysis tools in ArcMap to combine all derived information of suitable areas. Fig 2 shows an example of a geoprocessing model of some geology input data.

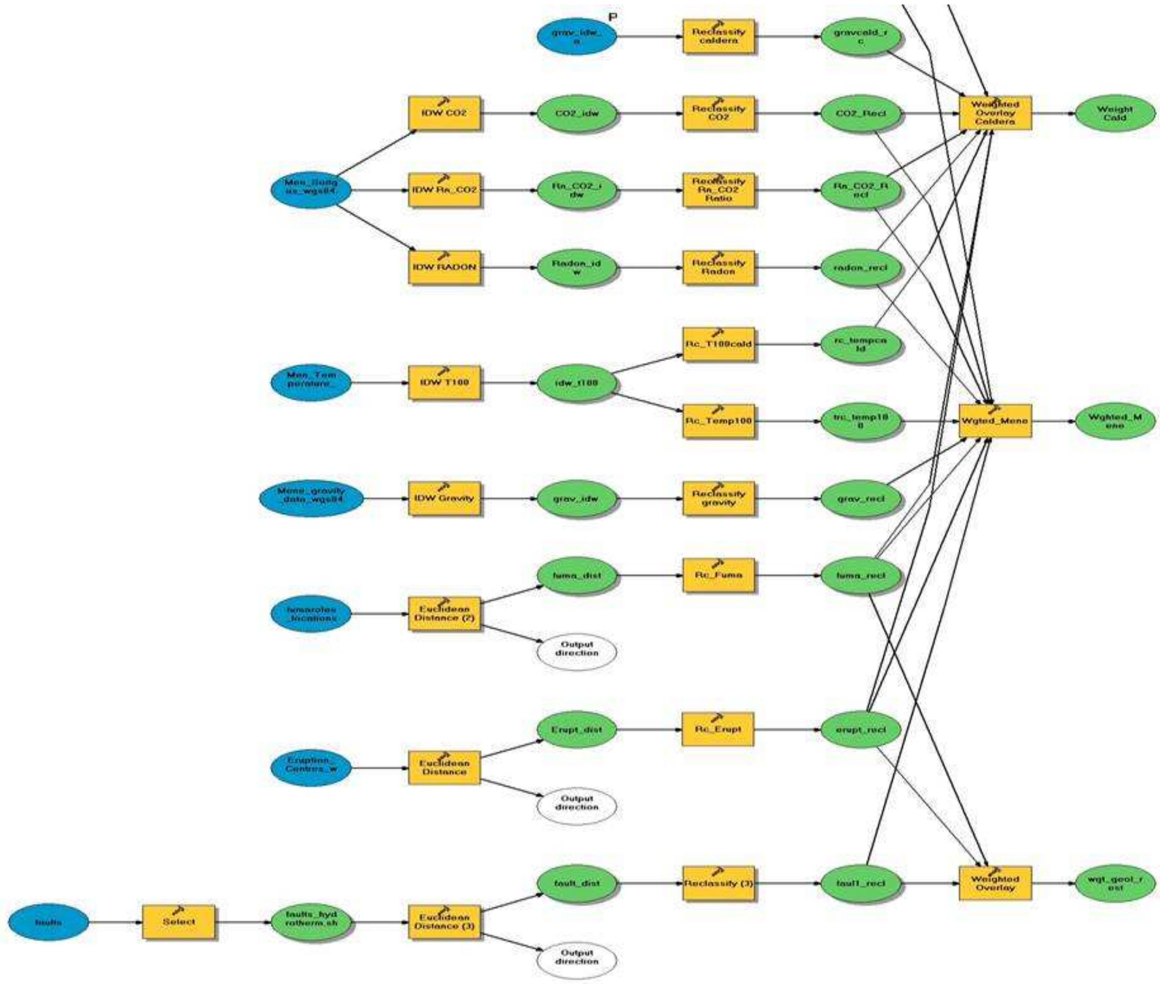


Figure 2: Suitability Model integrating geoscientic 'positive areas'

Intermediate results

Geology Suitable Areas:

Geology dataset included classifications of faults into hydrothermal active or non-active, distances from fault and fracture due to subsurface permeability distribution, eruption centers and fumarolic activities (Figure 3)

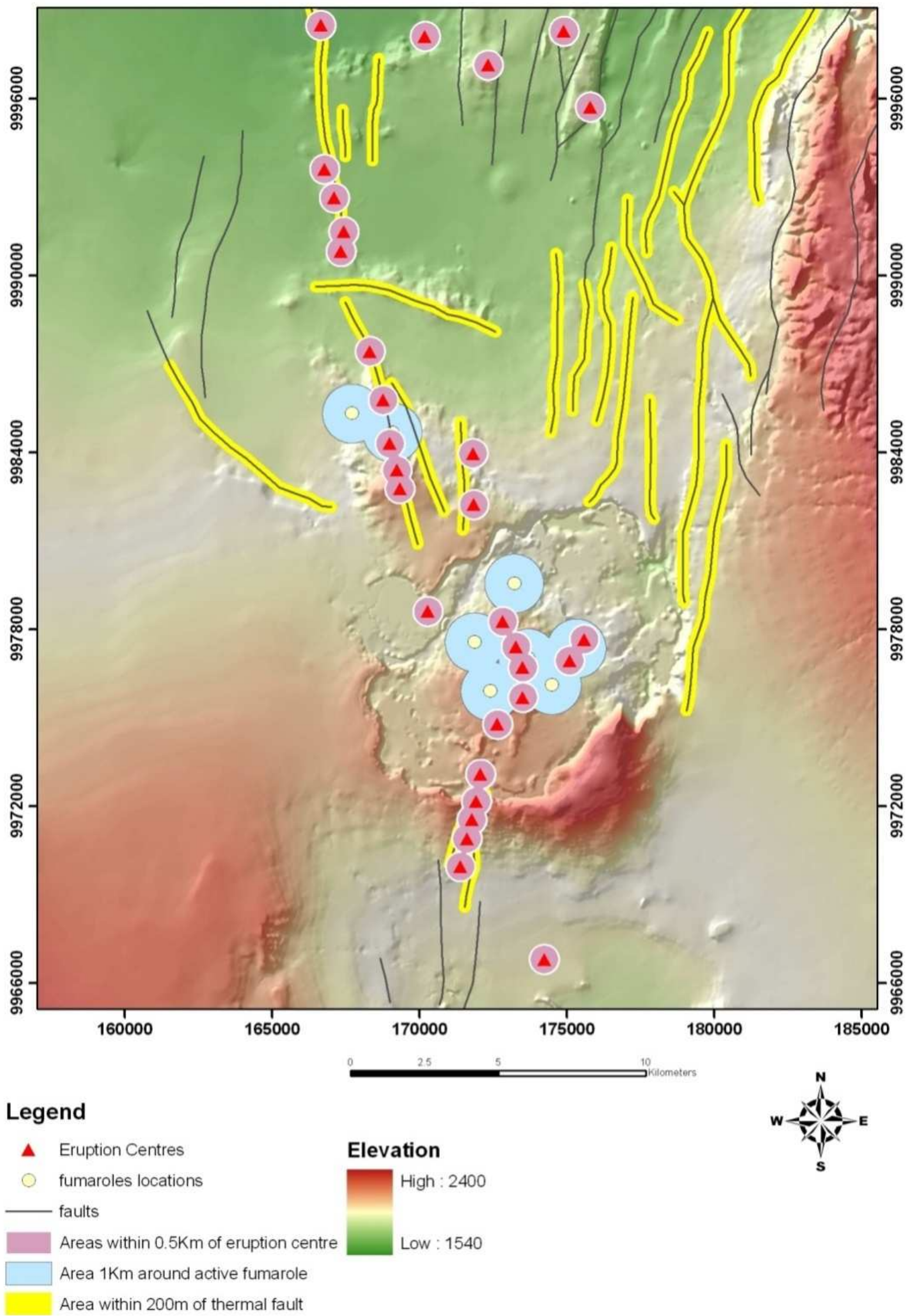
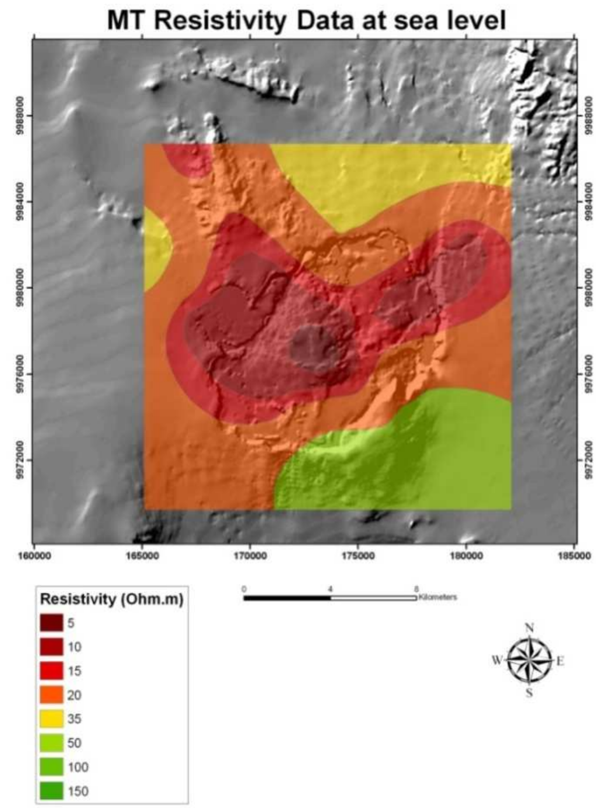
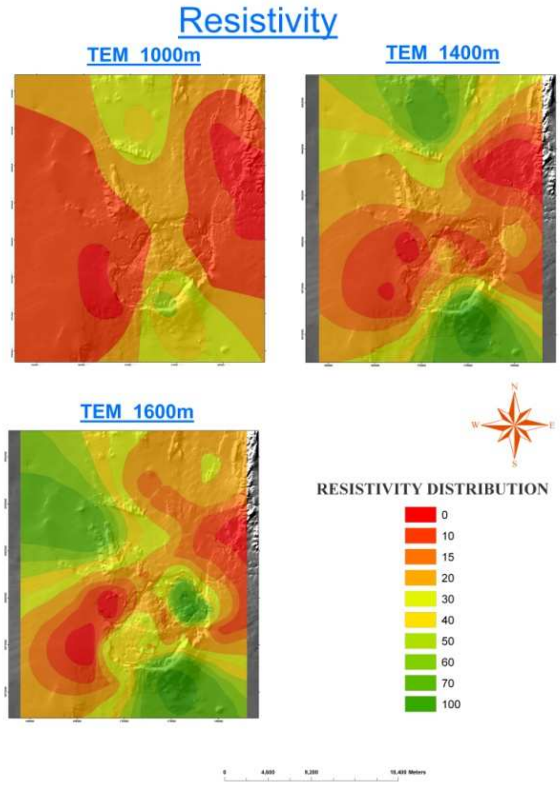


Figure 3: Showing geology data suitable areas.

Geophysics

Geophysics data used were MT and TEM anomaly maps integrated with Bouguer gravity map to derive positive areas





Bouguer Gravity Map of Menengai Caldera

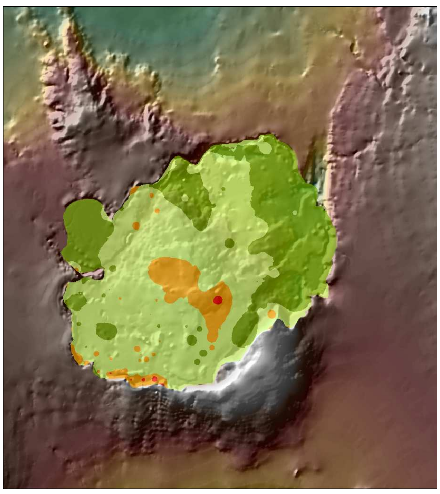


Figure 4: Geophysics data suitable areas:

Geochemistry

Geochemical parameters used include soil gas and fumaroles chemistry

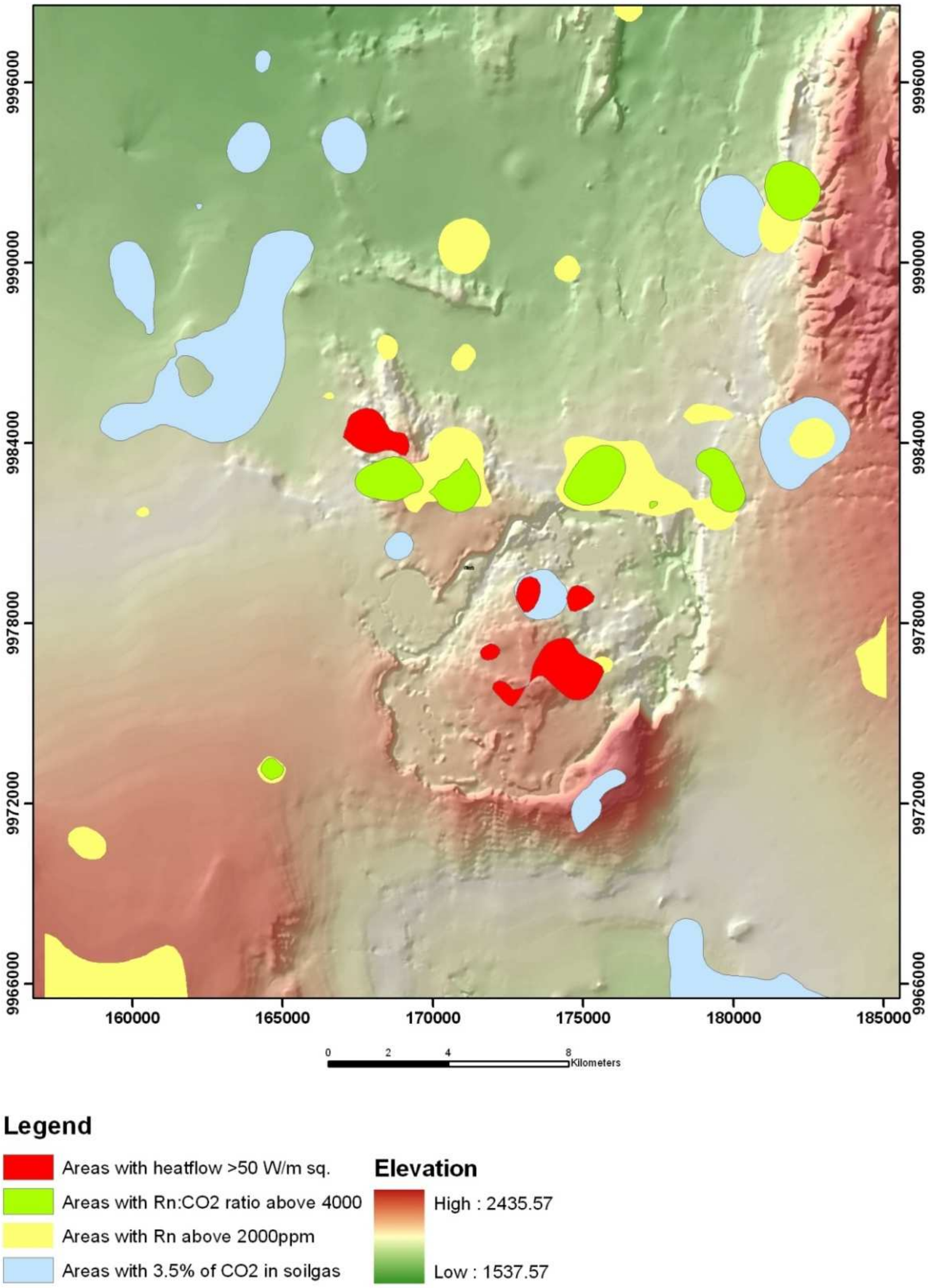


Figure 5: Geochemistry data and high heat flow suitable areas:

DATA INTERGRATION

Integration of data involves the logical combination of intermediate map products into a single suitability map. The procedure involves use of statistical and analysis tools to combine all information on the positive areas. Normally a measurement from a given method may be given a higher confident on interpretation of a geothermal system than the other. For instance, MT resistivity sounding at 2km depth tells more on the hydrothermal activity at subsurface than fumarole temperatures measured on the surface. The suitable areas derived from the model are put through reclassification and weighted overlay process. Statistical weighting applied to the various data depends on the target depth and type of well. For shallow wells of less than 500m deep, derived data from some methods will have different weighting from wells that target 1500 m to 3000 m depth.

Geological suitable area was determined by integratingthe selected areas (buffered distances) based on eruption centers, fumarole locations and faults maps. These layers were overlain and the selected areas werecombined to identify geologically suitableareas. A suitability map based on geologicalinvestigations is shown in fig. 3. Geophysical suitable area was determined byoverlapping of the MT and TEM resistivity soundings together with bouguer gravity anomaly maps by using the analysis tools. The selected areas weremerged to identify the geophysical suitable area for siting geothermal wells. A Geophysics positive areas map is shown in fig. 4. Reservoir science derived positive area map, showing heat flow of > 50W/m sq. was combined with that of geochemistry suitable areas obtained by integratingselected areas of Radon and CO2 ratios maps. These layers were overlainand the selected areas were combinedto produce the geochemical and reservoir science suitable area map. A suitabilitymap based on reservoir science and geochemistry is shown in fig 5.

Weighted overlay table

Raster	% Influence	Field	Scale Value
Reclas_Rn222a	25	VALUE	
		1	1
		8	8
		9	9
		10	6
		NODATA	NODATA
Reclas Fumarole	15	VALUE	
		1	1
		6	6
		9	9
		10	1
		NODATA	NODATA
reclas_faults (2)	40	VALUE	
		1	1
		3	3
		9	9
		10	1
		NODATA	NODATA

Sum of influence: 100 — Set Equal Influence

Figure 6: Weighted Overlay statistical table

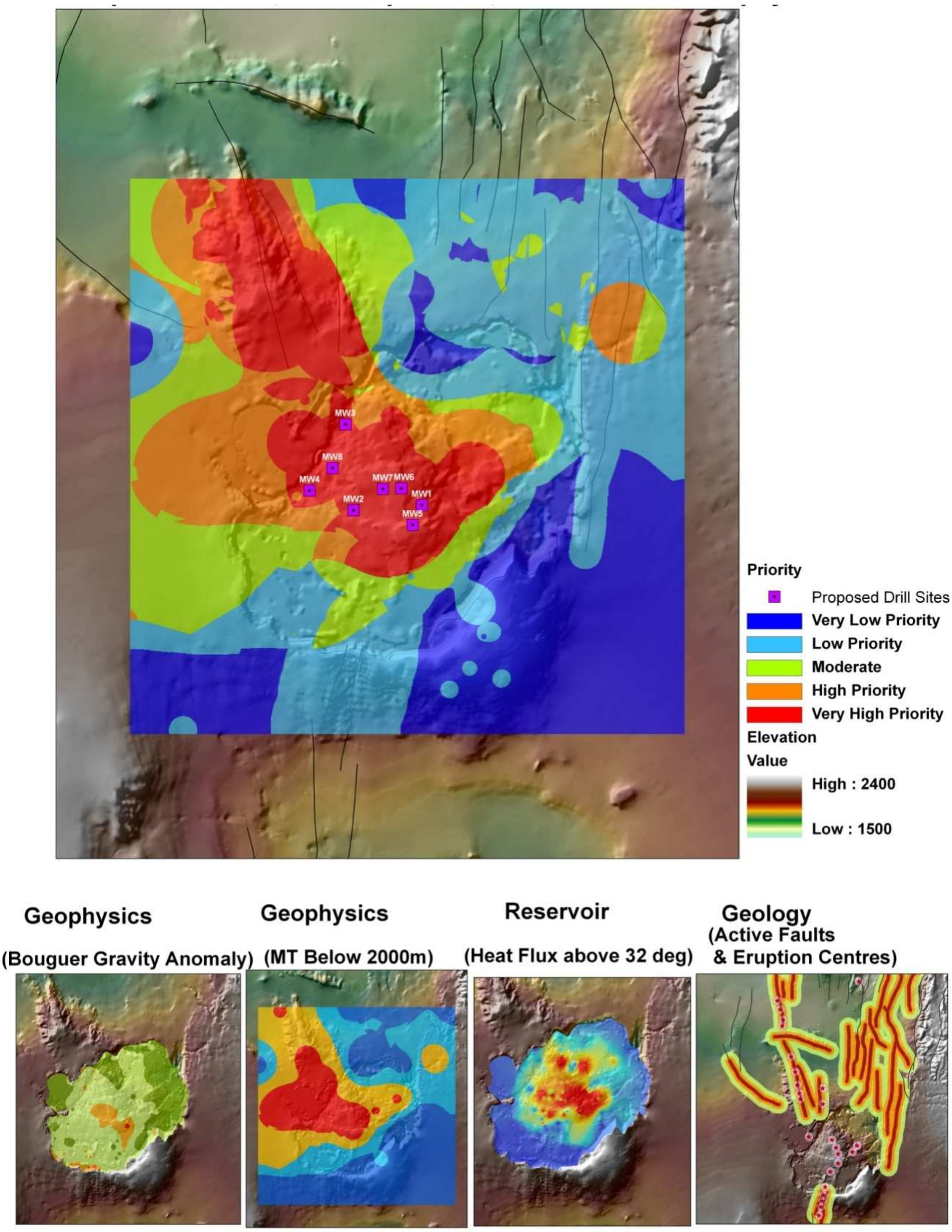


Figure 6: Shows priority areas for geothermal well sites in Menengai prospect

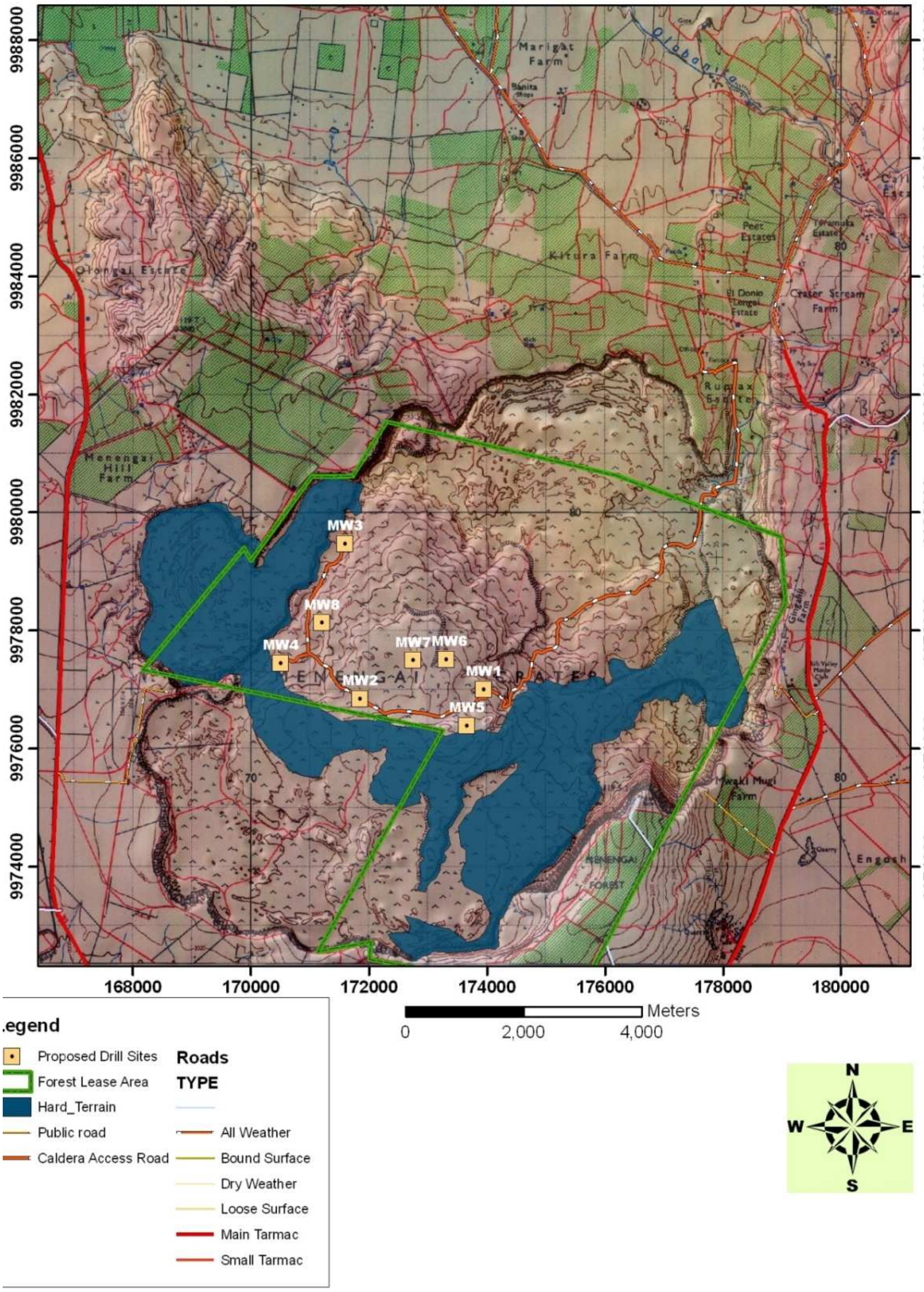


Figure 7: Map showing proposed geothermal well drill sites in Menengai prospect.

CONCLUSION

Geothermal exploratory drilling sites in Menengai prospect were investigated and identified by usingavailable geological data (structures, eruption centers, volcanic rocks, and faults), geophysical data consisting of Gravity, MT and TEM anomalies, and geochemical data such as soil gas samples, hydrothermalalteration zones, fumaroles and hot springs.

GIS was used to integrate these geo-scientific datasets in a suitability model for selecting best geothermal well sites.Eightgeothermal well drill sites werefinally identified.Observations on the final suitability model product show that the highest priority areas lie along zones of geological and tectonic significance. Since data integration process is quite automated, human bias is minimal and hence can be scientifically relied upon. The suitability model is dynamic andcan be enhanced even more by adding newdata layers to derive more relevant information useful for development of geothermal in Menengai prospect. The final priority map would normally be used by decision makers with emphasis on the available data.

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