INVESTING IN EXPLORATION GEOSCIENCE AND INNOVATION: A GIS-BASED GEOTHERMAL RESOURCE PRIORITISATION TOOL FOR TOHOKU REGION, JAPAN

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ABSTRACT

We have designed, built and are now utilising a GIS-based geothermal resource prioritisation tool for the Tohoku region, Northern Japan. For the first time, we have a toolbox for automating the integration of large, scientifically diverse, multi-sourced public and institutional geospatial datasets, that support Baseload Power's geothermal resource prospectivity assessment process. We assign weighted numerical values to resource, infrastructure and development variables aiding identification of geothermal systems, many overlooked for more than onsen bathing, with attributes for scaled, modular plant electric power and community-driven direct use applications.

The Tohoku region of northern Honshu boasts several hundred hot spring areas, but geothermal development has been hindered by community concerns, limited grid availability and uncertainties regarding development potential and resource viability, despite a large volume of historical and recent surface surveys and subsurface geoscience (including well data). Our approach facilitates integration of the various datasets, which can be visually presented in an unbiased assessment or as generated resource favourability scenarios. This provides Baseload Power with a unique advantage to identify geothermal areas of interest, initiate an appropriate exploration strategy, and engage with individuals, communities, industry collaborators and regulators early in the project management process, in order to meld appropriate (ORC, binary or other) technologies, our commercial goals, and the aspirations of local and development partners.

1. INTRODUCTION

Japan includes many geothermal regions. Most of them are within Quaternary volcanic and Tertiary volcanic zones, where 0.2 % of Japan's total energy generation is supplied by twenty geothermal power plants located in seventeen different areas. Most of Japan's high temperature geothermal resources occur in two regions. The first region goes from north to south in eastern Japan (from Hokkaido, via the eastern half of Honshu Island, to the Izu Islands), and the second one runs from Kyushu Island to the Southwestern Islands (Sugino and Akeno, 2010; Tamanyu et al., 2000). In these zones, it is assumed that heat is generated by Quaternary andesitic or dacitic volcanism and plutonism. Many hot springs and fumarole fields are located within Quaternary volcanic zones, which confirm the magmatic heat source of the geothermal activity (Kiavarz Moghaddam et al., 2014). These regions have a higher potential for geothermal exploration.

Baseload Capital Sweden AB is a specialised investment entity. It works globally to build and operate renewable heat power plants, with a focus on securing investment and funding to advance geothermal opportunities. Baseload Power Japan KK (BPJ) currently operates two geothermal plants, one (as an integrated brown-field bottoming cycle development Waita, Kumamoto-ken, Kyushu), and the other as a stand-alone plant in partnership with an onsen hotelier (in Midori, Gifu-ken, Honshu).

Amongst the greatest challenges for geothermal utilisation for electric or heat power are the costs and risks associated with resource evaluation, notably decisions premeditating exploration and development drilling. There are more than 2000 hot spring systems in Japan, with many used for a range of onsen tourism, agricultural and other direct use initiatives. Some have potential for electric power generation, which melds with the aspiration of BPJ to establish itself as a leading developer in Japan of low enthalpy geothermal power. The key to our success will be the unbiased identification of those hot spring systems with resource attributes conducive for development of sustainable, geothermally-sourced baseload electricity, especially those which meld with community aspirations.

To achieve our goals, BPJ commissioned GNS Science (GNS) to collaborate on and design a GIS-based geothermal resource prioritisation tool – this paper describes its build and application. BPJ decided to focus initially on the Tohoku region (Figure 1), with development of a toolbox for semi-automating the integration and analysis of large, scientifically diverse, geospatial geothermal datasets, collected over several decades, that exist for the region. Tohoku boasts several hundred hot spring areas, but geothermal development has been hindered by community concerns, limited grid availability and uncertainties regarding resource viability. Our approach facilitates the integration of the multi-sourced public and institutional datasets, which can be visually presented in an unbiased assessment or as resource favourability scenarios. Our approach provides BPJ with a unique advantage to identify geothermal areas of interest, initiate an appropriate exploration strategy, and engage with

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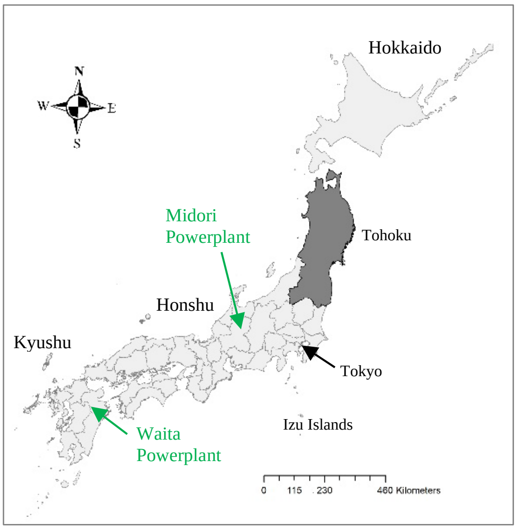

Figure 1. Map of Japan showing the location of the Baseload power plants and the Tohoku Region.

individuals, communities, industry collaborators and regulators early in the project management process.

2. LITERATURE REVIEW

Geothermal resource researchers have been applying GIS based prioritization and decision-making techniques as a means of evaluating geothermal resources for many years. Noorollahi et al. (2007) used a GIS-based resource prioritization tool to investigate regional-scale geothermal resources in the Akita and Iwate prefectures of northern Japan. The objective of their study was to determine the relationships between geothermal wells and geological, geochemical, and other geoscience layers and to use this integration of data to identify promising areas for geothermal exploration. The results found in this study show that 97% of currently productive geothermal wells in Akita and Iwate prefectures are located within the first priority zone selected by the tool. Kiavarz and Jelokhani-Niaraki, 2017 applied GIS-based ordered weighted averaging (OWA) approach to geothermal prospectivity mapping also for Japan's Akita and Iwate prefectures. The use of the OWA approach provides a model that generates geothermal prospectivity maps with different confidence levels. The researchers proposed a framework which involved developing and normalizing criteria maps and then specifying criteria preferences (i.e weights) and ORness values for computing order weights. The value of ORness indicates the degree of risk in the decision-making process. The GIS-based OWA model was used to integrate the criteria maps and decision makers' preferences into an overall assessment of each location for developing a variety of geothermal prospectivity maps. By specifying a value of ORness, the decision-maker can control the level of risk and generate either a low or high-risk geothermal prospectivity map. The property of either risk-taking or risk-aversion could be suitable depending on the need to find a larger number of potential locations with lower levels of accuracy (the higher percentage of wells and lower prediction rate) or find lower number of potential locations with higher level of accuracy (the lower percentage of wells and higher prediction rate). The results indicated that the values of wells percentages in high favorite areas for the most pessimistic and optimistic strategies are 85% and 100%, respectively. Regarding the prediction rate, the results showed that the rate for the most pessimistic and optimistic strategies were 18.55 and 1.18, respectively. Our GIS-based prioritization approach differs in that our toolbox and workflow include automation, integration, processing, and analysis of more varied geospatial data as well as covering the entire region of Tohoku. In our tool each layer is weighted based on its relative influence and combined with other layers to produce favorability ranking of the area of interest.

3. METHODOLOGY

3.1 Theory/Software

The toolbox uses a combination of customised Spatial Analysis toolsets from software ArcGIS Desktop Advanced (developed by ESRI). The strength of a computerised approach is the ability to semi-automatically combine an indefinite number of geospatial variables that influence the solution to a given problem. The method is based on the creation of individual maps of variables ranked using a 1 to 5 scale, where 1 represents the least favourable and 5 the most favourable. Each layer is weighted based on its relative

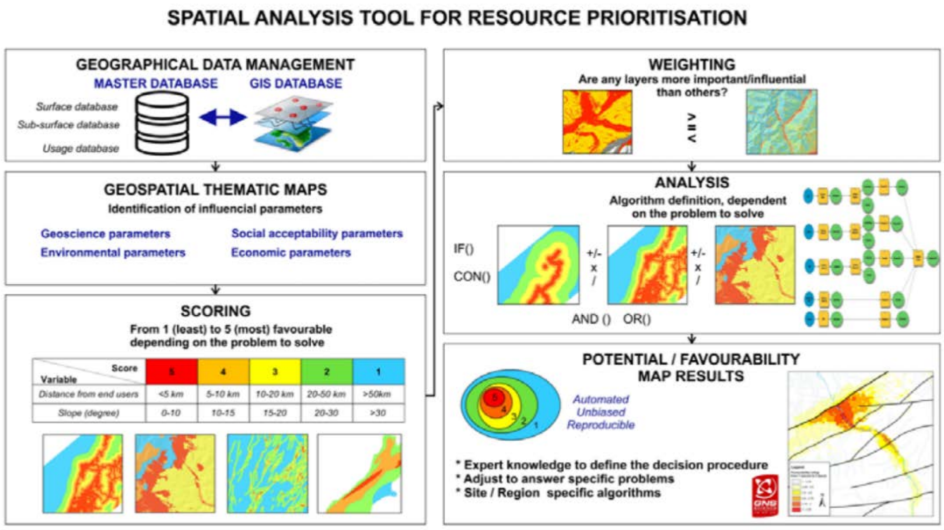

Figure 2. Workflow of spatial analysis for resource prioritization

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influence and combined with other layers to produce a favourability ranking of the area of interest (Figure 2).

3.2 Input Data

3.2.1 Tohoku GIS data and storage

The majority of the geothermal and geoscience layers are from the geothermal resources dataset produced by the Geological Survey of Japan (GSJ), which can be found here https://www.gsj.jp/Map/JP/geothermal_resources.html. The active faults layer was obtained from https://gbank.gsj.jp/activefault/. Administrative, elevation and topographic layers were obtained from a number of sources including the geospatial information authority of Japan (GSI) (https://www.gsi.go.jp/kankyochiri/gm_japan_e.html), the ministry of environment (MOE) (https://www.env.go.jp/earth/ondanka/rep/index6.html) and the Ministry of Land, Transport, Tourism and Industry (MLIT) found here https://nlftp.mlit.go.jp/index.html.

In this study several layers created based on previously interpreted data are used. For example the geothermal resources layer has been defined by Tamanyu et al. (2000) as: Type I: Geothermal resources area related to Quaternary volcanoes, Type II: Geothermal resources area not related to Quaternary volcanoes, Type IIA is located west of the volcanic front, Type MB is for features located east of the volcanic front and Type III: Deep-seated hot water resources in late Neogene to Quaternary sedimentary basins. Type I and Type II are further ranked based on measured spring temperature and calculated chemical geothermometer temperatures: Rank A: high-temperature hot springs (>90°C), Rank B: medium-temperature hot springs (>42°C) and high chemical geothermometer temperatures (>150°C), Rank C: medium-temperature hot springs (>42°C) and low chemical geothermometer temperatures (<150°C) (Tamanyu et al., 2000).

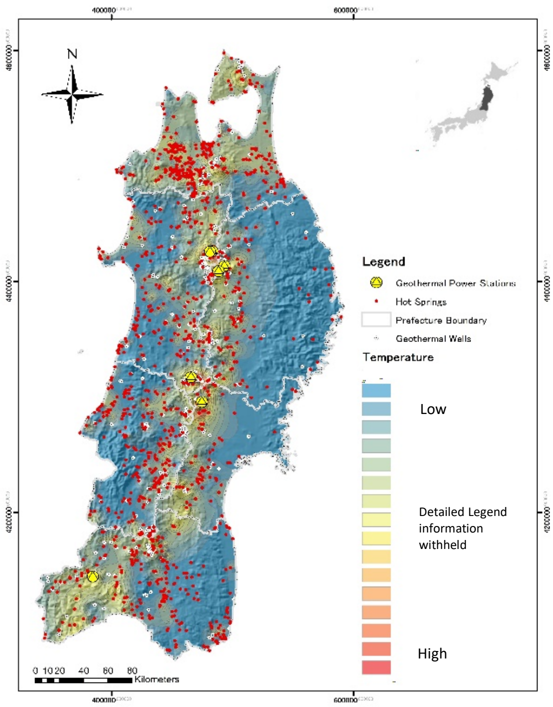

Figure 3.Wells, power stations and temperature.

Three input databases were created to store the input data used by the toolbox. One stores the geoscience layers (for example geothermal wells, hot springs (Figure 3), geological units, faults and quaternary volcanic centers, (Figure 4)), and the

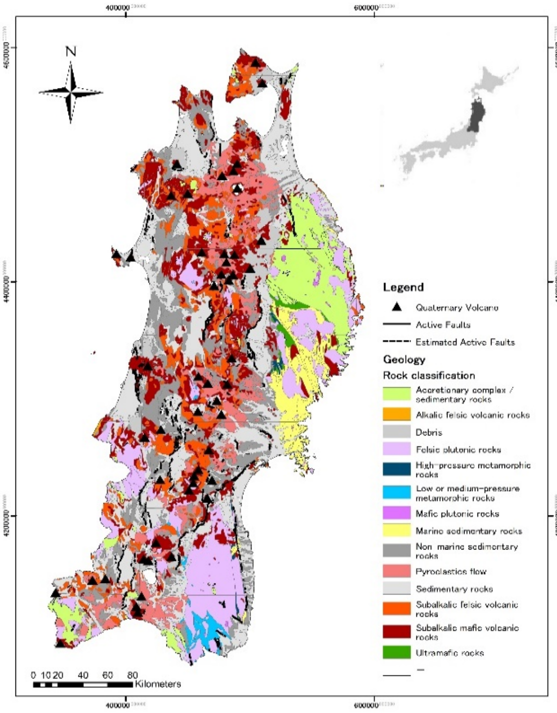

Figure 4. Map of Tohoku showing geological layer.

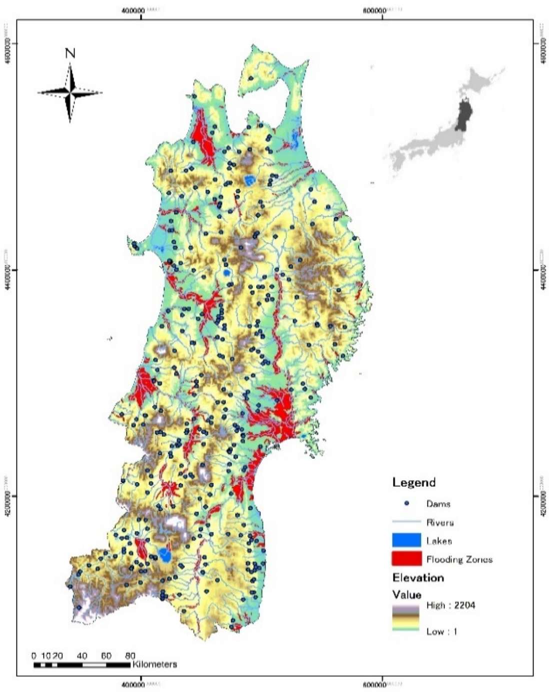

Figure 5. Map showing Tohoku infrastructure layers.

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additional two store the environmental layers, infrastructure and other relevant use layers (for example environmental hazards, location of dams, rivers, lakes and elevation (Figure 5)).

3.2.2 Preprocessing of Input data

The input data used for the analyses covers the area of interest as continuous layers of either categorical information or numerical values. Pre-processing of the data to format it and/or transform it into a useable variable is not included in the toolbox, as it is dependent on the properties of each layer and the variable of interest associated with that layer (Figure 6).

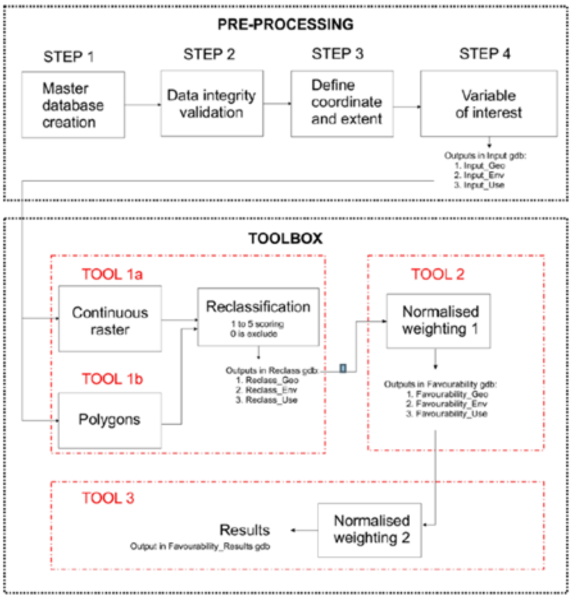

Figure 6. Preprocessing of data and custom GIS toolbox workflow.

Layers can be combined based on simple and/or complex spatial combination. The data were transformed into variables of interest using a combination of the following techniques: Computation of distance from a feature (e.g. distance from the active faults), computation of spatial density of a feature (e.g. density of onsen), interpolation of contour layers into continuous grids (e.g. gravity contours), categorisation in classes of interest (e.g. landcover), combination of layers and categorisation (e.g. natural hazard layers) and complex combination of layers and classification (e.g. combined geochemical signature). In order to combine geochemical signatures, we first decided on key elements of interest to us: Cl, pH, Ca, SiO_2, HCO_3+CO_3 and the Quartz Conductive geothermometer. Classes were then assigned to combinations of these elements: areas of high HCO_3+CO_3 (>316.2 mg/Kg) and low Cl (<31.62 mg/Kg) are class C. Remaining areas of high Cl (>316.2 mg/kg), high SiO_2 (>100 mg/Kg) and high QzCond (>125°C) are class B. Remaining areas of high Cl (>316.2 mg/kg), low Ca (<31.62 mg/kg), pH above 4 and low HCO_3+CO_3 (<100 mg/kg) are Class A and all other remaining areas are Class D). Following transformation (if needed) the user of the toolbox must then prepare layers into one of two formats: Categorical polygon layers (e.g representing geological units) or numerical grids (e.g distance to hot springs, wells or slope). Once data has been preprocessed into an appropriate format it is then ready for input into the favourability toolbox.

3.3 Favorability toolbox

3.3.1 Tools 1 A and B

The GIS Favourability toolbox created by GNS is designed to be user-friendly with a customised sequence of four tools that the user follows to process the spatial data iteratively and sequentially. Once the layers are converted into a categorical polygon layer or a numerical grid layer they can then be reclassified into ranking values which can be assigned to the appropriate variable within the layer (Figure 7). Ranking values are from 1 (low) to 5 (high). 0 is for an exclusion zone

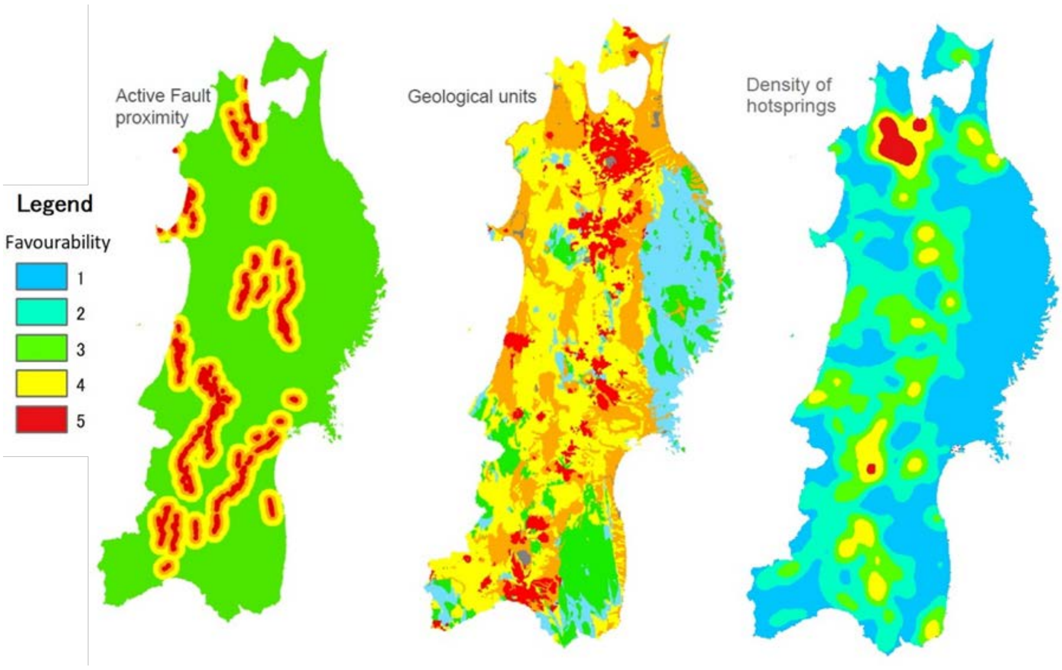

Figure 7. Maps showing results of layer processing using tools 1a and b.

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(not suitable for development) and -1 is for no data. The reclassification is done using two tools: tool 1a processes vector polygon data with a text attribute representing different categories (e.g. geological units, land use) and allows for the reclassification of these categories into the ranking scheme. In the case of the geological units: higher values were assigned to younger volcanic rocks while lower values were assigned to older sedimentary, volcanic and metamorphic rocks. Tool 1b processes continuous raster grids (e.g. active fault proximity) and allows for reclassification and is saved automatically in one of three reclass geodatabases: environmental, geoscience or layers related to infrastructure or others. Figure 8 shows the interface of tool 1a.

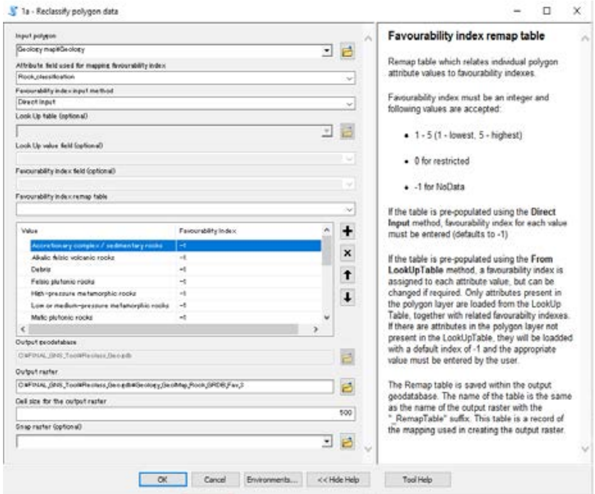


Figure 8. Tool 1a interface.

3.3.1 Tool 2

This tool allows for the combination of all/some layers within one Reclass geodatabase using normalised weighting, based on their respective influence (Figure 9). Weighting for each input grid is entered as a positive integer or decimal number, knowing that values are relative to each other and normalised when the weighted sum is calculated. The output favourability rating is a decimal number in the same 1 to 5 range as the input grids, with zero representing restricted areas. The favourability maps produced by tool 2 for the geosciences, use and environmental groups are shown in

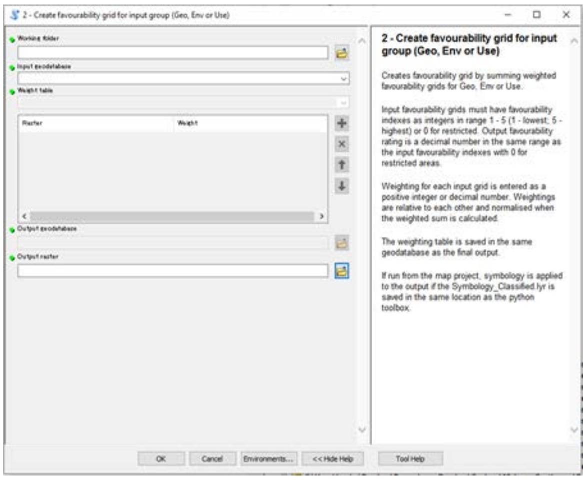
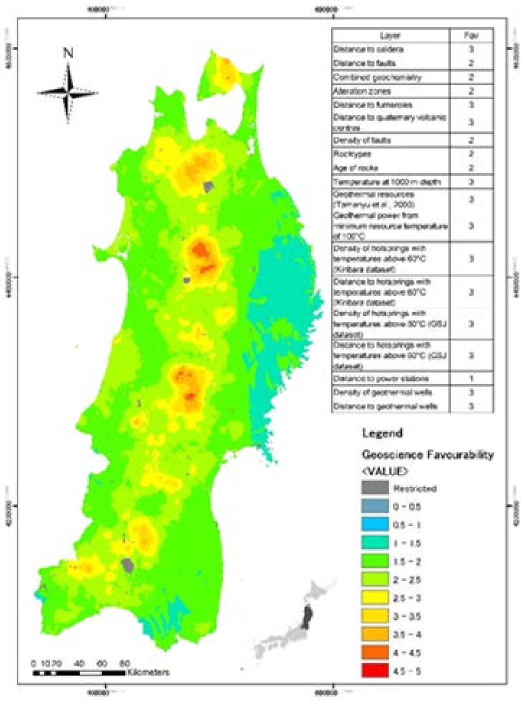


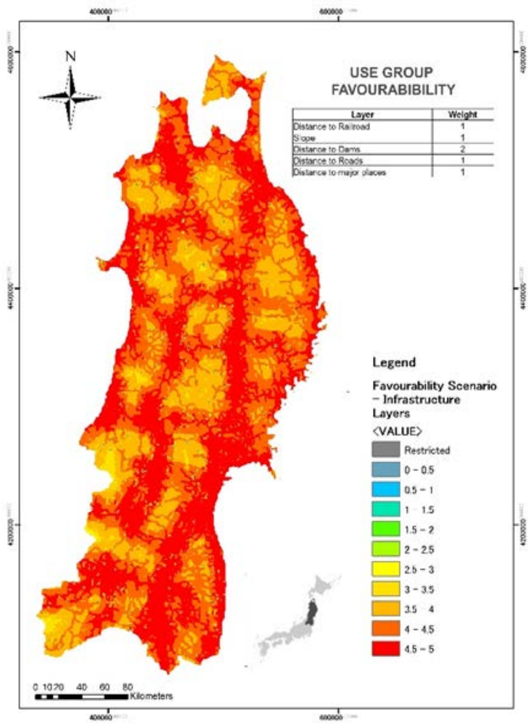
Figure 9. Tool 2 interface.

Figures 10, 11 and 12. The different layers used and their respective values assigned for favourability are shown.



Layer	Fav
Distance to caldera	3
Distance to faults	2
Combined geochemistry	2
Alteration zones	2
Distance to fumaroles	3
Distance to quaternary volcanic centres	3
Density of faults	2
Rocktypes	2
Age of rocks	2
Temperature at 1000 m depth	3
Geothermal resources (Tamanyu et al., 2000)	3
Geothermal power from minimum resource temperature of 100°C	3
Density of hotsprings with temperatures above 60°C (Kinbara dataset)	3
Distance to hotsprings with temperatures above 60°C (Kinbara dataset)	3
Density of hotsprings with temperatures above 50°C (GSJ dataset)	3
Distance to hotsprings with temperatures above 50°C (GSJ dataset)	3
Distance to power stations	1
Density of geothermal wells	3
Distance to geothermal wells	3

Figure 10. Geoscience Favourability Map



Layer	Weight
Distance to Railroad	1
Slope	1
Distance to Dams	2
Distance to Roads	1
Distance to major places	1

Figure 11. Use Group Favourability Map

The aim of the usage favourability map is to act as a proxy for potential grid availability hence why distance to roads, railroads and major population centres are included.

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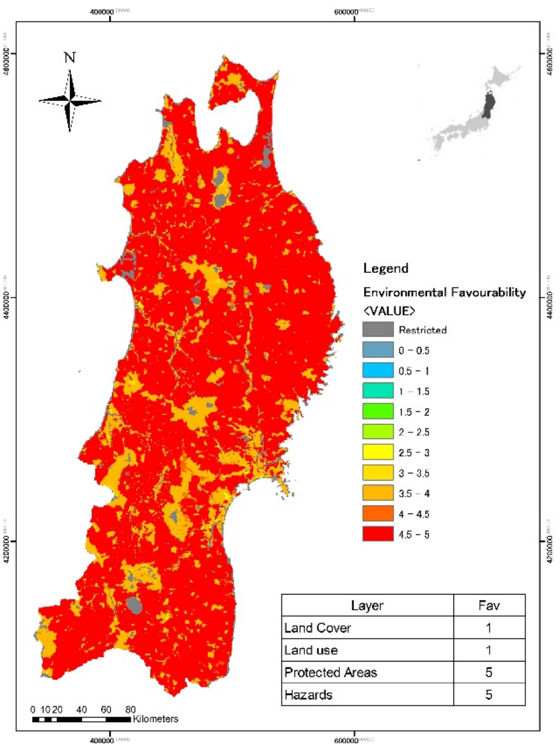

Developments must also not be in close proximity to hydroelectric dam infrastructure.

3.3.1 Tool 3

This tool allows for the combination of all/some of the favourability grids created by Tool 2. Tool 3 (Figure 13) combines the geosciences, use and environmental favourability maps to produce the final integrated favourability map. The map highlights a number of areas of interest for further geothermal exploration. In practice, this last tool sums and weights the pre-weighted geosciences and/or environmental and/or usage grids. The output favourability rating is a decimal number in the 1 to 5 range, with zero representing restricted areas.

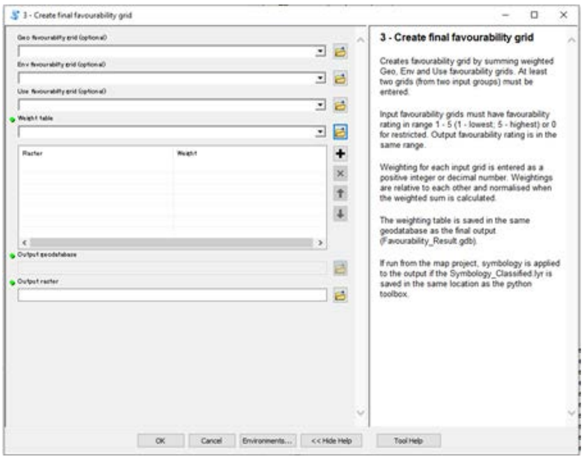

Figure 13. Tool 3 interface.

5. RESULTS AND CONCLUSION

We have designed, built, and are now utilising a GIS-based geothermal resource prioritisation tool for the Tohoku region, Northern Japan. For the first time, we have a toolbox for automating the integration of large, scientifically diverse, multi-sourced public and institutional geospatial datasets, that support Baseload Power's geothermal resource prospectivity assessment process. We assign weighted numerical values to resource, infrastructure and development variables aiding identification of geothermal systems, many overlooked for more than onsen bathing, with attributes for scaled, modular plant electric power and community-driven direct use applications.

The toolbox uses a combination of customised Spatial Analysis toolsets from software ArcGIS Desktop Advanced (developed by ESRI). The strength of a computerised approach is the ability to semi-automatically combine an indefinite number of geospatial variables that influence the solution to a given problem. The method is based on the creation of individual thematic maps of variables ranked using a 1 to 5 scale, where 1 represents the least favourable and 5 the most favourable. Each layer is weighted based on its relative influence and combined with other layers to produce a favourability ranking of the area of interest. The final favourability map created by the tool highlights a number of areas of interest for further geothermal exploration in the north, central north and central areas of Tohoku.

6. LOOKING AHEAD…

We will continue to work on the tool with GNS to improve functionality in terms of ease of use as well as automating the data preprocessing. We will also apply the methodology to create and further expand the favorability mapping to Kyushu as well as Hokkaido in the future. The tool requires reliable input data so as more data is obtained, the databases as well as favourability maps for Tohoku can be updated in the future.

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