Enhancing regional and national economic development from mineral projects: The use of spatial analysis to inform on infrastructure deficit in Canada

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Abstract

A Canada National Infrastructure spatial analysis has been completed for the Prospectors and Developers Association of Canada (PDAC). The objective was to identify the Canadian districts where strategic investment in enhancing the infrastructure network could stimulate the development of new mines by reducing the overall capital costs of production. This was achieved by spatially analysing the relationship between infrastructure deficient regions and the location of significant, undeveloped mineral deposits.

After compiling a comprehensive dataset of the existing infrastructure in Canada, the available information was classified and weighted based of their importance to mineral extraction. The most relevant datasets – including infrastructure, elevation and climatic data as well as cultural data such as distribution of population – have been combined using spatial modelling techniques to create a "remoteness" map of the country. The "remoteness" map has then been compared with potential mining/advanced exploration projects in order to identify areas where strategic investment by provincial and federal government could stimulate new mineral development and therefore regional economic development. The completed spatial model has highlighted where investment would be most beneficial. Furthermore, a series of more specific cost-related maps have been produced for two categories of mineral commodities, precious minerals and base metals. The two categories differ in mining methods and quantities of minerals extracted; therefore requiring different types of infrastructure for operating. These additional models show the percentage increase of potential costs for building and maintaining a mining project related to the increase in remoteness. The results of the heat maps clearly identify regions where the enhancement of specific types of infrastructure could drastically decrease the overall costs of a precious mineral or base metal project and therefore encourage its development by making it economically feasible.

The model results will allow the PDAC to work with appropriate government departments to prioritise the most prospective mining opportunities in infrastructure deficient areas and therefore efficiently propose a workflow of possible enhancements to local infrastructures to encourage the development of new mines in the identified areas.

Keywords: mineral targeting, spatial modelling, economic development, infrastructure, mining, Canada.

Introduction

The objective of the model was to create a national infrastructure study for Prospectors and Developers Association of Canada (PDAC) to identify those Canadian districts where strategic investment in infrastructure could encourage the development of new mineral deposits, increasing the value of the mining industry to the economy. MinEx Consulting Pty Ltd approached Kenex Ltd (Kenex) to assist in the project by developing spatial databases of existing infrastructures, mines and deposits, and to perform spatial analysis for identifying areas with infrastructure deficits and the relationships of the deposits to those areas. The lack of infrastructure is associated with higher capital and operating costs that may become a major constraint to developing new mining projects in these remote regions.

Spatial modelling techniques were used to complete the study. These techniques take into account all the available relevant infrastructure data in Canada and combine them in a Geographic Information System (GIS) to identify areas lacking infrastructure. Creating a map of remote and undeveloped areas (referenced in the study as “remoteness map”) involves a large number of variables and incorporation of multiple data sets. The primary consideration is the distance of a site to existing road, rail, transmission networks and/or ports and airports; then other important parameters need to be considered, such as the terrain complexity between the site and existing infrastructure, the presence of permafrost, climatic conditions, population density and the distribution of waterways and restricted areas, including national parks and reserved land. Each separate factor can have a varying degree of influence on the economics of a project depending on the needs and requirements of different deposits. With the complexity of analysis required, the use of expert weighted spatial modelling (Fuzzy Logic) was selected as the most appropriate method to create the required output. The first output of the spatial modelling created a general remoteness map for the entire country, highlighting remote areas and providing information about the types of infrastructure these areas are especially lacking. The resulting map was then compared with the locations of known mines and undeveloped deposits to identify potential areas of interest that could become economically important with a strategic investment in infrastructure.

Furthermore, a set of cost maps has been created for two different commodities: precious minerals and base metals. The two categories differ in mining methods and quantities of minerals extracted; therefore they necessitate different types of infrastructure for operating. The new set of maps took into account the mining requirements of each commodity type and spatially calculated the potential increase of capital and operating costs associated with the distance from the key types of infrastructures for each commodity. The results aimed to give a better understanding of the economic impact of the remoteness on the development of a mining project, showing at the same time how investing in specific types of infrastructure could potentially unlock projects for precious minerals, base metals or both commodities.

Remoteness map of Canada

Data sources

The study included an initial compilation of infrastructure data and other data of relevance for determining the remoteness of an area. The compilation included publicly available data for Canadian infrastructures, mines and deposits, climate, elevation and cadastral information. A number of parameters were then defined as important for successfully finding undeveloped remote areas:

- Infrastructure data: distance from roads and type of closest roads; distance from transmission lines and stations; distance from railroads and type of rails; distance from ports and airports facilities.
- Topographic barriers: elevation; complexity of the surrounding terrain and slope; waterways and lakes.
- Climatic variables: yearly minimum temperature and its distribution; permafrost distribution.
- Cultural data: population indexes and distribution; natural parks and restricted areas.
- Known mines and undeveloped deposit locations.

The data was managed in a GIS and manipulated using techniques such as buffering, grid extrapolation, grid interpolation, map classification and focal neighbourhood statistics.

Fuzzy logic modelling

The study area for this project consists of the entire land mass of Canada. For the modelling, a 500 m by 500 m resolution grid was generated over the country. The resolution of the grid was chosen as appropriate for a national scale model, balancing the high resolution of the infrastructure and terrain analysis against the practicalities of data management and computer processing and the resolution of the output maps.

Spatial data modelling was undertaken using the Fuzzy Logic technique developed by Bonham-Carter of the Canadian Geological Survey (Bonham-Carter, 1994). This was done using the Spatial Data Modeller extension (ArcSDM) for ESRI's ArcGIS for Desktop software. Fuzzy Logic relies on expert opinion to derive weights that rank the relative importance of all the variables considered in the model. The datasets used are reclassified based on their values and the expert's knowledge, and then a weighting value (0-1) is assigned to each class. The weight expresses the degree of importance of the various classes as predictors of the feature under consideration. These predictive maps can be combined by a variety of Fuzzy Logic operators (fuzzy AND, fuzzy OR, fuzzy gamma, etc.). The operator determines how the model statistically combines the input maps to create the final map, which identifies areas with the highest probability relevant to the feature being modelled (Figure 1).

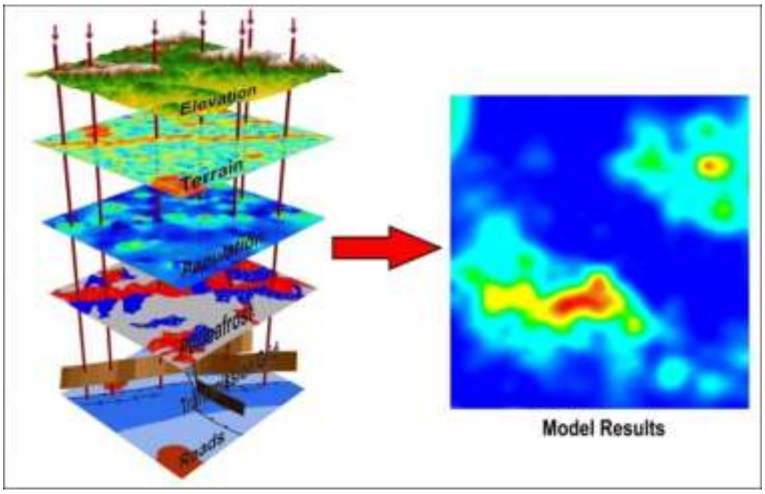

Figure 1. Thematic maps weighted and combined using Fuzzy Logic operators to create a predictive map.

Table 1. Explanation of Fuzzy Logic weights.

Weight	Description
0.001-0.01	Any predictive map with this weighting will exclude this cell.
0.1	A cell with this weight will only result in a ranked cell if all other predictive maps have high weights.
0.5-0.9	A combination of these weights will produce varying degrees of suitability, e.g. If all cells have weights of 0.8 or 0.9 then the output cell will be classified as highly prospective.
1	1 is not used as a weight for any of the predictive maps in this model because it assumes a perfect ability of the data to predict infrastructure locations.

For this model, 22 weighted predictive maps were created, using the available data to represent as many of the identified factors affecting the economic development of remote areas as possible. Each map represents a feature and contains classes of values for that feature. Expert opinion was used to weight each class based on its importance. The weights and their general effects are summarised in Table 1. The resulting weighted predictive maps were then combined using the Fuzzy operators OR, AND and Gamma in order to produce the final remoteness map of the country (**Error! Not a valid bookmark self-reference.**).

Table 2. Explanation of Fuzzy Operators.

Fuzzy Operator	Description
AND	The minimum of the fuzzy memberships from the input fuzzy rasters.
OR	The maximum of the fuzzy memberships from the input fuzzy rasters.
PRODUCT	A decreasive function. Used when the combination of multiple evidence is less important or smaller than any of the inputs alone.
SUM	An increasive function. Used when the combination of multiple evidence is more important or larger than any of the inputs alone.
GAMMA	The algebraic product of the fuzzy Sum and the fuzzy Product, both raised to the power of gamma (between 0 and 1).

Predictive Modelling Outputs

The 22 predictive maps created for the relevant spatial data were classified and weighted according to Richard Shodde's feasibility analysis of existing operating mines (Schodde, 2015) and then combined to create the final map of the remoteness for all of Canada. The workflow of the spatial model is explained in **Error! Reference source not found.**. The steps outlined below were followed in the model to obtain the remoteness map:

- The predictive maps for road, rail, port and airport were combined together with the Fuzzy operator OR in order to create an inclusive map of the distribution of all the transportation infrastructures in the country. In this map, the value of each cell represents the distance of that cell from any type of transportation network.
- In a similar way, the predictive map for power lines and stations were combined using the Fuzzy operator OR in order to create a map for the transmission network. This map also represents the distance of each cell from any type of power transmission.
- The three terrain maps – elevation, slope and terrain complexity – were combined using the Fuzzy operator Gamma with a value of 0.8[1]. The Gamma operator accounts for not only the weights of the classes in each map but also the combination of weights between different maps, giving the best overview of terrain conditions for each cell of the map.
- The climate parameters, permafrost and minimum temperature, were introduced in the model to identify areas with challenging climate features. For this reason, the climate maps were combined using the Fuzzy operator AND[2]. This operator prioritizes the lower weighted classes over the others and therefore creates a climate map where each cell represents the least favourable climate condition between the two maps.
- The derived maps – infrastructure, transmission, terrain and climate – have been combined with the population density map (shown as a cultural map) using the Fuzzy operator Gamma (0.8). The resulting map is the remoteness map for the entire country as shown in Fig. 3.

[1] The algebraic product of the Fuzzy Sum and the Fuzzy Product, both raised to the power of gamma (between 0 and 1).

[2] The minimum of the Fuzzy memberships from the input fuzzy rasters.

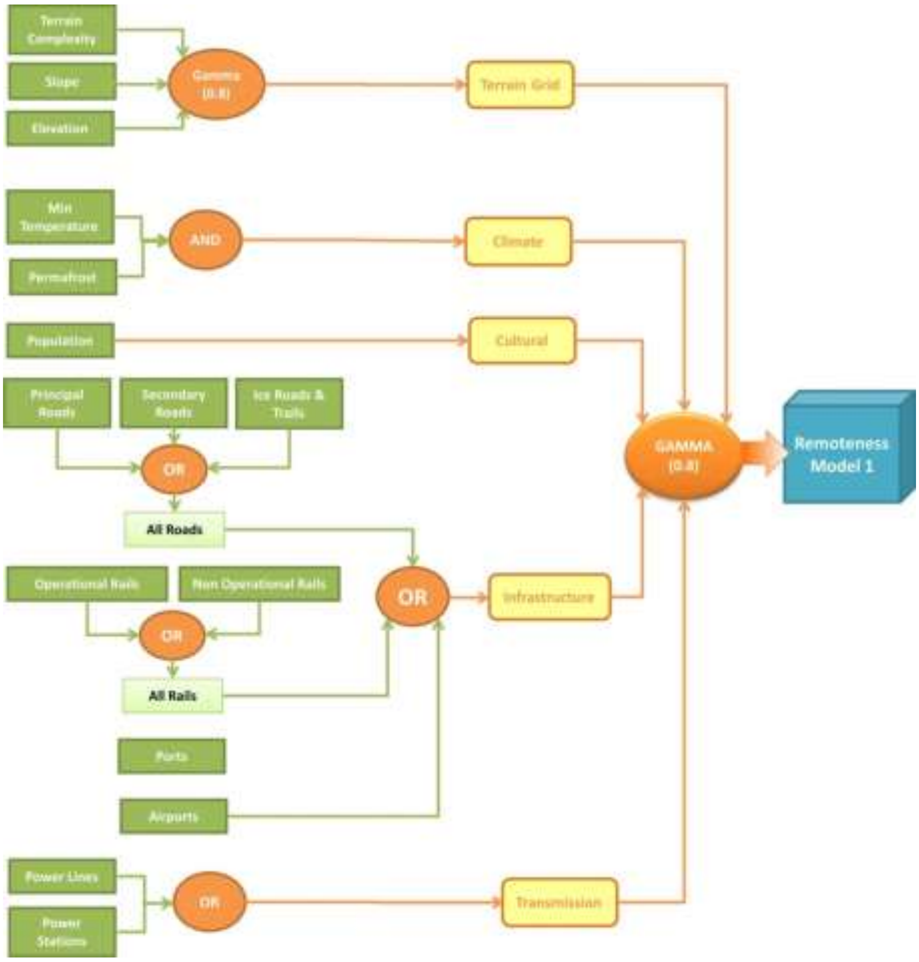

Figure 2. Diagram of the model procedure.

The remoteness map is the initial result of the study. It highlights areas where the infrastructure is present and well developed (dark blue), areas that are instead remote with a very low level of infrastructure (bright red) and a series of areas in between with varying degrees of development. These intermediate areas, which can be identified on the map with a range of colours from light blue to yellow, can be viewed as the most economically feasible places for a potential enhancement of the already existent infrastructure or the construction of new facilities. The remoteness map has then been used for comparison with the locations of operating mines and undeveloped deposits (Figure 4) in order to identify the most prospective regions for developing new mining projects with relevant funding from the local government. Table 3 shows the number of projects for each category that fall in the different bands of remoteness, from highly remote to high density of infrastructure, giving a solid preliminary indication about how many new projects could be unlocked with investment in infrastructure for different types of remote areas.

Table 3. Comparing operating and undeveloped & feasibility deposits with the remoteness map.

Class	Number of Operating Mines	Undeveloped and Feasibility Deposits
Highly remote	0	38
Remote	5	58
Mildly remote	6	159
Presence of infrastructure	21	250
High density of infrastructure	73	465

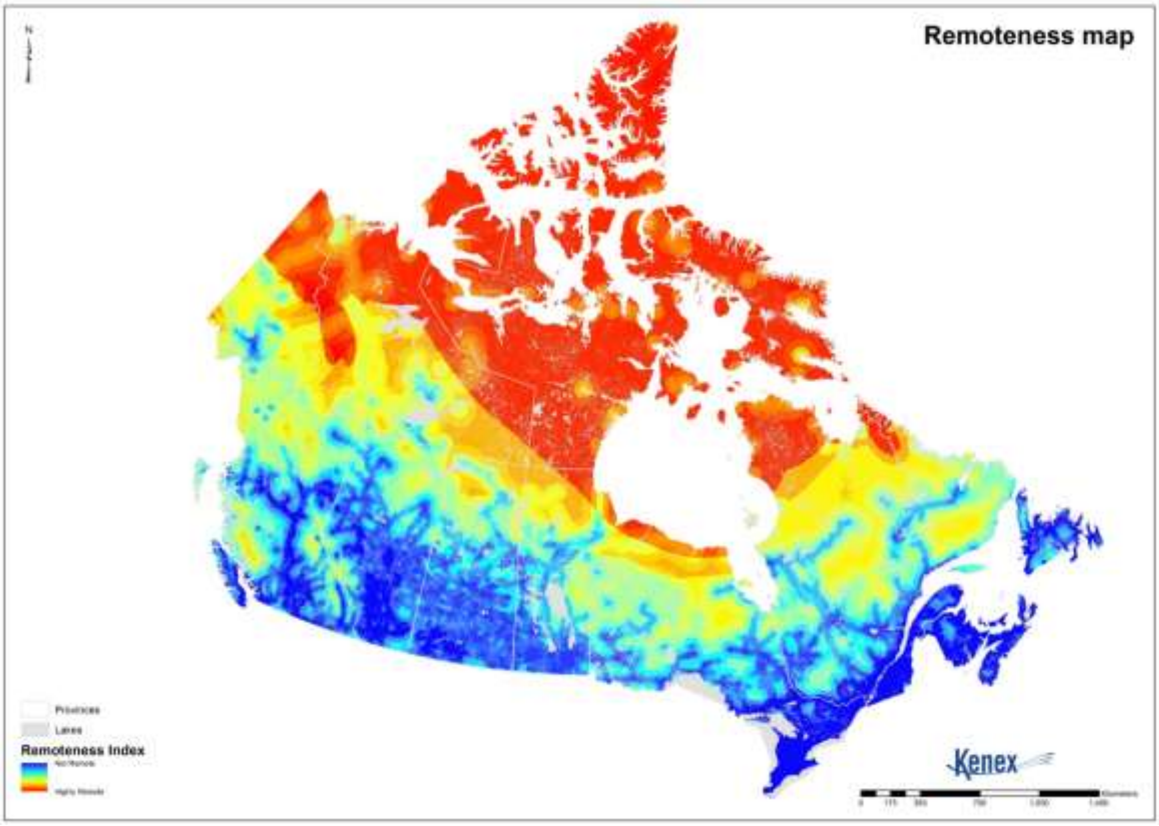

Figure 3. Remoteness map of Canada.

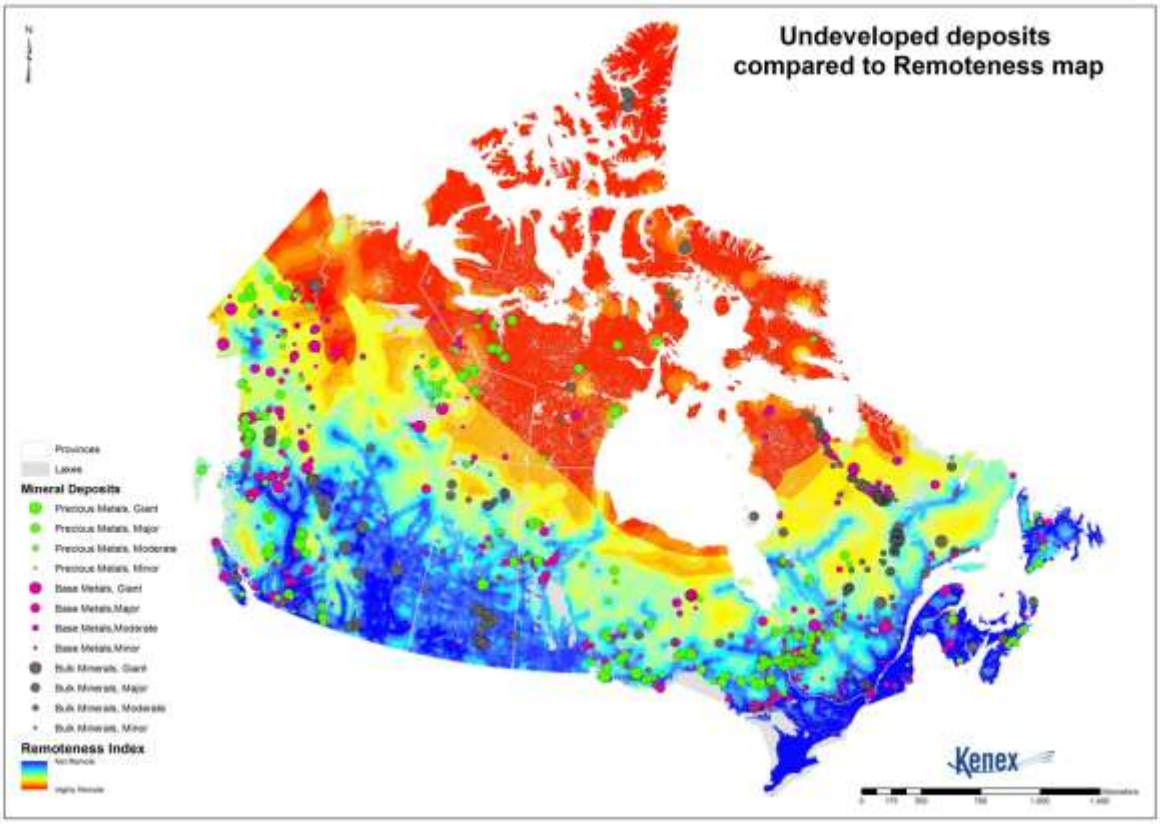

Figure 4. Undeveloped deposits compared to the remoteness map.

Precious minerals and base metals cost maps

Comparing the remoteness map to locations of feasibility and undeveloped projects provides a useful first approach to identify key areas where the development of infrastructure can create potentially economic projects. However, the remoteness map does not account for the costs of construction or maintenance for mines of various commodity types and the potential for costs to increase with respect to the distance from the infrastructure required to develop an economically suitable mine. For this reason, more detailed cost maps have been developed for the two commodity types analysed in this study, precious minerals and base metals.

These maps have been generated using calculations and weightings provided by MinEx Consulting. A set of assumptions for the cost associated with increasing remoteness for each commodity type have been derived from analysis of operating mine profiles. General assumptions and methodologies have been used for all commodity types, but the parameters analysed vary for each commodity due to the importance of specific types of infrastructure in mining different commodity types.

The estimated costs for each of the weighting factors have been normalised to observe the potential impact on the head-grade required in order to determine if the project can be considered economic. A mine that has a perfect supply of infrastructure surrounding it will have a normalised grade of 1; there will be a percentage increase the further the project is located from the required infrastructures. The normalised grade is used to show how the distance from each considered type of infrastructure might have an impact on the economic potential of a project, independently from the mineral market oscillations and the actual cost of the studied infrastructures. Therefore, the normalised percentage increase of grade needs to be interpreted as an indication of construction and maintenance costs of the mine, and not as the actual grade value of the mined mineral.

For the capital costs nine factors were considered in creating the final maps. Each of them represents the cost of building new infrastructure around the mine site depending on the distance of the mine from the existent infrastructure:

- Power: calculating the cost of connecting a mine to the power grid versus building a diesel generator based on the distance from the existing grid.
- Roads: representing the costs of building a road for connecting the mine to the existing network. The roads must be differentiated in normal road and ice roads – less expensive to build but more expensive to maintain – which have to be constructed in permanent permafrost areas.
- Storage: this parameter is used only in the capital costs of a base metals mine located in a permanent permafrost region. It calculates the cost of building stockpile facilities at mine sites serviced by ice roads – that only operate for 4-8 weeks per year – versus the cost of building an all-weathered road to the road network or the coast.
- Airports: calculating the cost of building a new airport or upgrading an existing one near the mine site.
- Sea ports: calculating the cost of building a new sea port or upgrading an existing one near the mine.
- Towns: calculating the cost of building a camp for the workers at mine sites too far from towns for commuting.
- General terrain effects: representing the possible increase in capital costs due to more difficult terrain conditions, such as mountainous areas or continuous permafrost.

For the operating costs, the heat maps give a broad overview of the costs associated with maintaining newly built or existing infrastructures during the life time of a mine. These costs are determined by multiple local factors and may change over time; therefore, the final maps aim to show a more generic estimation of the increase in operating costs. For these maps, four main parameters have been considered; each of them represents the cost of maintaining the infrastructure at the mine site depending on the distance of the mine from the existent infrastructure:

- Power: calculating the cost of maintaining a diesel generator for the mine sites located in areas too far away from the existent transmission network.
- Roads: calculating the cost of maintaining a road, both in non-permafrost and in continuous permafrost regions.
- Inbound and outbound material: calculating the cost of transporting goods to and from the mine site based on the distance from the main cities and ports and the best possible routes to follow.
- Fly in-fly out: related to the distance from towns, represents the cost of flying people (and material) from the provincial capitals to the mine site.
- General terrain effects: representing the possible increase in operating costs due to more difficult terrain conditions, such as mountainous areas or permanent permafrost.

Furthermore, the geography of Canada needs to be considered when reviewing both the capital cost and the operating cost parameters: new projects situated on the islands and peninsulas near the Arctic Circle will be extremely remote and therefore will have different requirements and costs compared to projects located on the mainland. For this reason, a different set of parameters and weightings have been used for the island region.

Capital and operating costs vary greatly depending on the size of the mine. As a rule, the percentage increase in grade is higher for small deposits than major ones. In order to give a more realistic representation of the difference in costs related to the deposit size, a separate cost map has been created for small, moderate and major deposits for each type of commodity. In this study, deposits are considered small if having a mining rate less or equal 0.35 Mtpa; moderately sized deposits have a mining rate of 1.75 Mtpa; major deposits have a mining rate of 4.9 Mtpa.

All the mentioned parameters have been weighted and combined together to create a capital cost map, an operating cost map and a final cost map for small, moderate and major deposits of precious minerals (Figure 5) and base metals (Figure 6). A summary of the type and number of deposits falling inside each percentage break of the final maps, as well as the ratio between the number of undeveloped projects and the total number of projects have been created comparing the final cost map with the deposit locations. This offers an overview of the impact of the overall costs in the development of economic projects (Table 4 and Table 5).

Table 4. Statistics and summary for major precious metals cost map.

Grade Increase	Area (km^2)	All	Closed	Operating	Un-developed	Undevelop Feasibility	Undevelop Other	Undeveloped/ All
0-10%	1,773,245	385	142	21	172	27	145	51.34%
10-20%	1,636,256	117	47	10	55	12	43	49.11%
20-30%	1,167,717	50	33	5	60	12	48	61.22%
30-40%	920,421	36	9	5	31	5	26	68.89%
40-50%	1,227,368	26	3	0	20	8	12	86.96%
50-60%	1,756,876	25	4	0	6	4	2	60%
60-70%	1,012,394	1	3	0	7	5	2	70%
70-80%	9,402	0	1	0	1	0	1	50%

Table 5. Statistics and summary for base metals major deposits cost map.

Grade Increase	Area (km^2)	All	Closed	Operating	Un-developed	Undevelop Feasibility	Undevelop Other	Undeveloped/ All
0-10%	93,919	20	4	0	16	4	12	80%
10-20%	923,268	283	138	19	126	16	110	44.52%
20-30%	1,374,508	142	71	5	66	11	55	46.48%
30-40%	1,303,836	89	21	5	63	9	54	70.79%
40-50%	1,399,056	59	6	4	49	12	37	83.05%
50-60%	1,512,637	56	4	1	51	9	42	91.07%
60-70%	1,286,278	21	2	2	17	5	12	80.95%
70-80%	809,735	7	0	0	7	0	7	100%
80-90%	560,206	6	0	0	6	1	5	100%
90-100%	133,489	1	0	0	1	1	0	100%

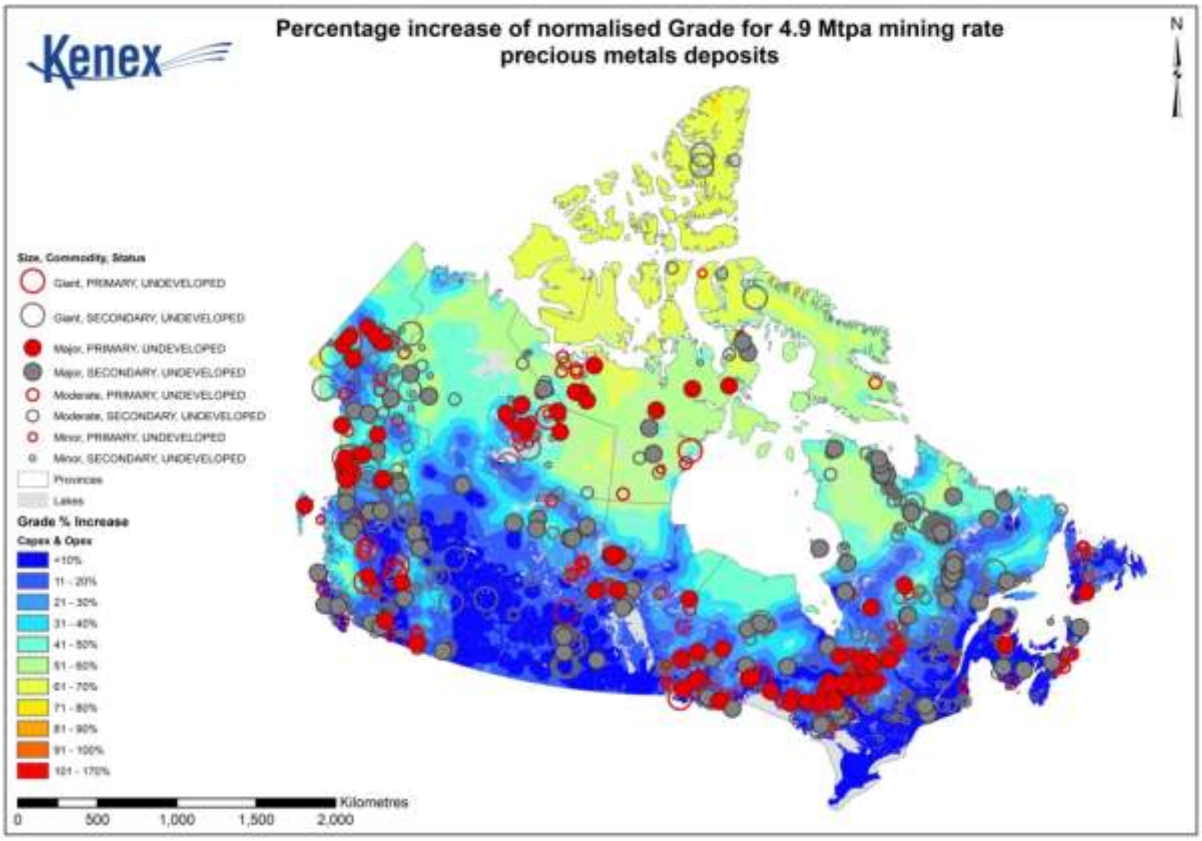

Figure 5. Final cost map for precious minerals major deposits.

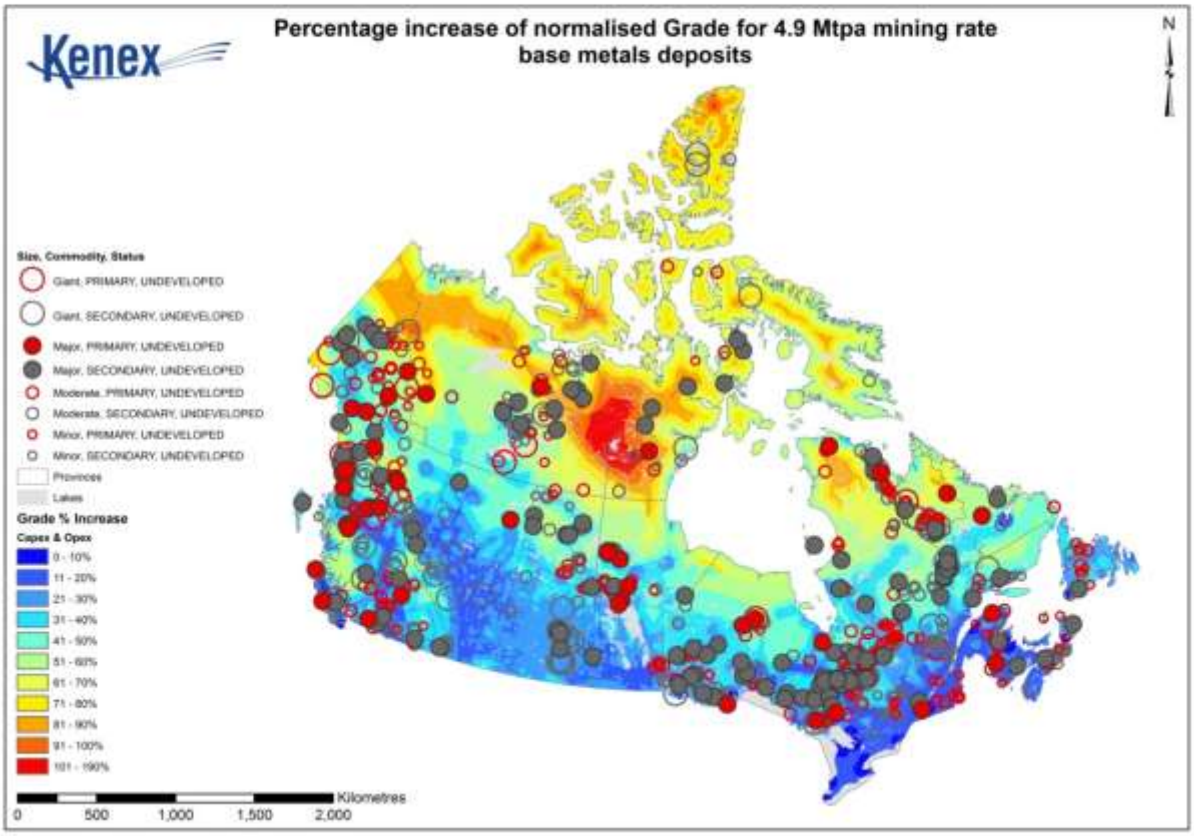

Figure 6. Final cost map for base metals major deposits.

Conclusion

The final cost maps, together with the initial remoteness map created in this study, are currently being used by PDAC to lobby the provincial governments of Canada to invest resources for enhancing or building specific types of infrastructure in specific regions. The results of this study clearly show where an initial investment from the government could unlock a series of mineral projects, which would be able to share the new or enhanced infrastructure and therefore decrease the capital and operating costs and make the current undeveloped deposits economically feasible.

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