Exploration targeting for small-scale Gold Mining Operations in the Dunkwa Area of Ghana

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The key objective of an investigation programme in Ghana was to develop new exploitation targets suitable for artisanal and small-scale mining. The method used can help drive similar activities in Ghana and in other countries.

Mining • Exploration • Geology • Artisanal and small-scale mining (ASM) • Case study • Ghana

1 Background

About 35 % of Ghana's annual gold production of 142 t (2019, [1]) comes from artisanal and small-scale mining (ASM) operations. This contributes substantially to Ghana's mining industry generated national income and is an important factor for poverty reduction and national development. Because of declining production figures, exhausting resources, and enormous ASM related environmental damage the Government of Ghana has launched the World Bank financed programme 'Ghana Artisanal and Small-Scale Mining Formalisation Project (GASMFP)', which is executed under the Management of the National Ministry of Lands and Natural Resources, and accompanied by the Ghana Geological Survey Authority. The generation of new exploitation targets suitable for ASM activities is one of the key tasks of this programme. The methodology and results presented here represent a case study and guideline for further similar activities throughout the country. They may also serve as a reference for similar activities in other countries.

2 Objectives and Survey Area Location

The objective of the current research is to identify new exploitation targets for small-scale mining activities in the Dunkwa mining area. Placer gold has been mined here, though the main valleys have now almost been completely mined out. New mining targets are being identified in small side valleys, in old river terraces and in basement rocks.

The survey area was initially identified using the 'Gold Potential Map of SW-Ghana' [2], as generated within the framework of a research project in 2013 by a consortium of the Geological Survey Department

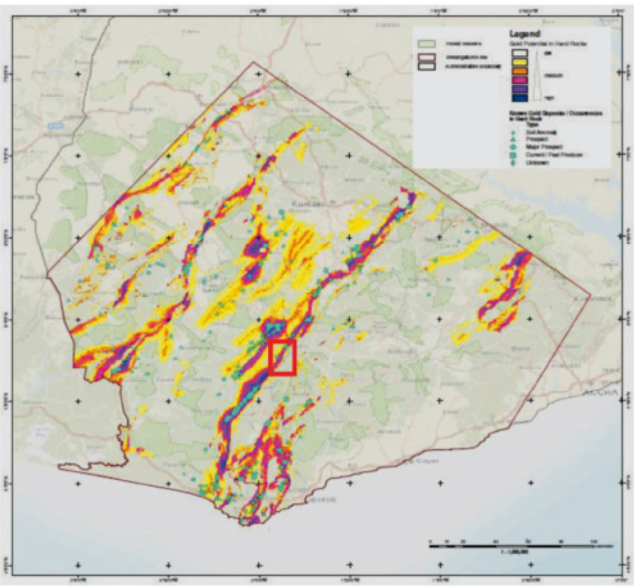

Fig. 1: Gold Potential Map of SW Ghana [2] showing the survey area

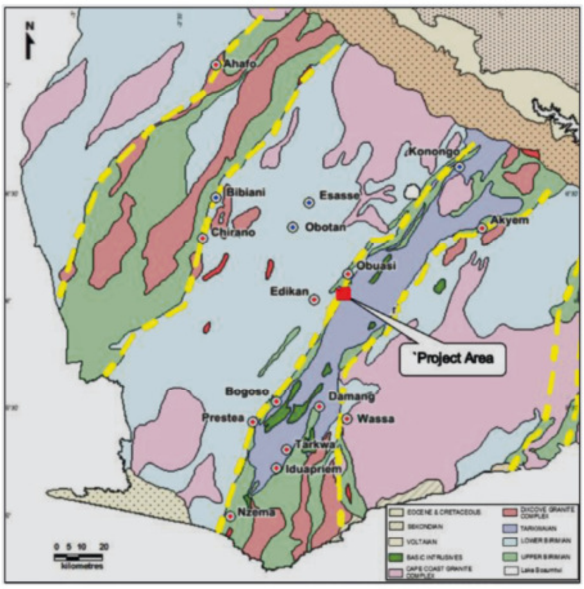

Fig. 2: Regional geological setting of the survey area

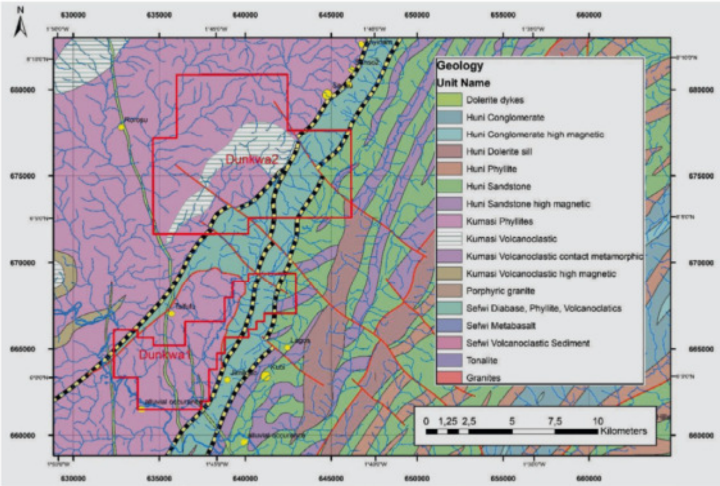

Fig. 3: Local geological setting

(Ghana), Beak Consultants GmbH (Freiberg, Germany) and the Technical University Freiberg (Germany) (**Fig. 1**). This area is located in the centre of the famous Ashanti gold belt. The survey zone covers an area of 115 km² and consists of two separate sections.

3 Geological Setting

The project area is located in south-western Ghana in the Man Shield (also referred to as Leo Shield) of the Precambrian West African Craton (**Fig. 2**). In Ghana, the Man Shield consists of seven mostly NE striking Paleoproterozoic greenstone belts of the Birimian Supergroup, emplaced from 2250 to 2170 Ma, separated by flyshoid basin sediments deposited during 2150 to 2100 Ma [3].

The Man Shield was affected by the Eburnean Orogeny resulting from convergence between the West African Craton and the São Luis Craton of South America, occurring during 2130-1980 Ma [3]. The early stages of this collision event resulted in thrust tectonism and crustal thickening. Uplift developed foreland basins in several of the greenstone belts in Ghana, particularly in the Ashanti Belt, which were subsequently filled with molassic sediments of the Tarkwaian Group deposited between 2132 and 2097 Ma [4]. Progressive tectonism evolved into a transgressional regime with thrusts developing into transcurrent faults and syntectonic plutonism plus metamorphism affecting both the Birimian and Tarkwaian stratigraphy.

Most of the gold in Ghana was emplaced relatively late in the Eburnean Orogeny [3, 5, 6] and principally in deformation zones in Birimian metasediments and metavolcanics and as paleoplacer (Witwatersrand-like) deposits in Tarkwaian braided fluvial quartz pebble conglomerates. To a lesser extent gold was emplaced within pre- and syntectonic granitoid intrusive bodies pervading the greenstone belts and within basin sediments along regional structures. Metallogenetically, the most important greenstone belt in Ghana is the Ashanti Belt.

The survey areas are located directly on the famous Ashanti Belt, between the cities of Kumasi in the Northeast (NE) and Dunkwa in the Southwest (SW). Geologically, the surrounding rocks belong to the Birimian Supergroup of the Proterozoic age. The areas are crossed by the Ashanti and Kubi shear zones. Major hard rock gold deposits are located NE and SW of the survey area [3].

The local geology is marked mainly by NE-SW striking metavolcanics and metasediments of the Birimian Supergroup (Kumasi phyllites, Sefwi diabase and volcanoclastics) and cut by mafic dykes (**Fig. 3**). This map was compiled using data from [7], and our own airborne geophysical data interpretation.

4 Legacy Data and Map of Minerals

Over the years many regional and local geological mapping, prospecting and exploration activities were carried

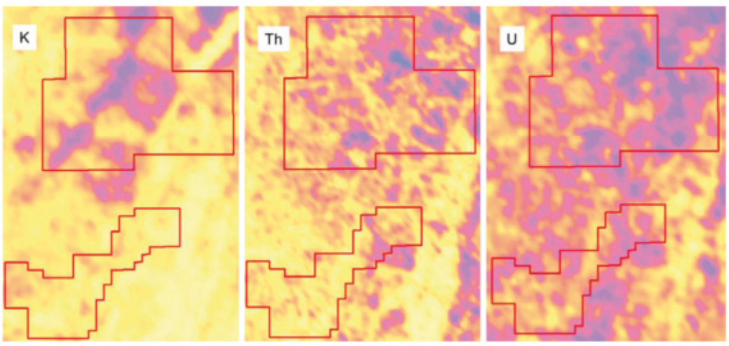

Fig. 4: Examples of geophysical datasets [13]
Th and U in ppm Equivalent, K in %

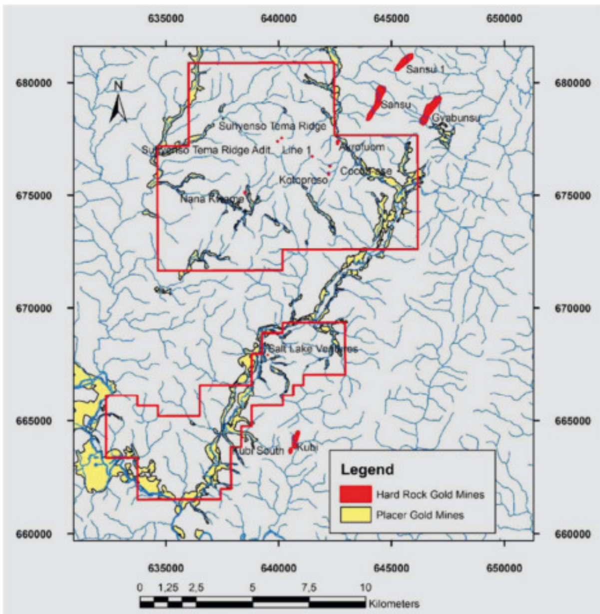

Fig. 5: The Map of Minerals of the Survey Area

out in and around the survey area [e.g. 8, 9, 19, 11, 12]. Unfortunately, the data obtained from these private exploration activities were not fully available for our project. The survey area is covered by geological maps of 1:100,000 scale and regional airborne geophysical data (magnetics and radiometry, [13], Fig. 4).

Using the publicly available remote sensing Sentinel data [14] and the available legacy data the Map of Minerals (Fig. 5) was created as the main input data set (the training data) for the initial artificial neural networks (ANN) based exploration targeting. The initial hard rock gold potential map was produced in conjunction with the regional geological and geophysical data.

5 Multistep Artificial Neural Network (ANN) based Exploration Targeting

Artificial neural networks (ANN) are an excellent instrument for the identification of exploration targets. The approach was implemented in Beak's advangeo® prediction software [15, 16]. The respective data processing workflow is shown in Fig. 6. Using known mineral occurrences as training features and pre-existing geoscientific data as controlling parameters exploration target maps have been compiled in an iterative process using the body of data as it grew during the project as follows:

- **At the beginning:** using the regional geophysical and geological data for general survey area identification
- **After legacy data collection:** for detailed planning of the field survey program
- **At the end:** consideration of all field data; for final exploration targeting and follow-up work program design

The interim target map was verified independently by the results of stream sediment sampling: the stream sediment Au anomalies match very well with the main ANN generated target areas. Results of ANN based exploration targeting, stream sediment, auger and soil sampling are mutually confirmative.

6 Field Work and Analytics

The field work was executed as a combination of stream sediment sampling, soil sampling, pitting, auger drilling, and hard rock sampling:

- The entire area was covered with a stream sediment survey (density 2 samples/km^2). Stream sediment data were processed as shown in Fig. 7: the sampling points were identified using the local stream network, the analytical results have been logarithmized, related to the respective catchment areas, and gridded to make them useable in the ANN based calculations.
- Multi-element analytics were performed at ALS laboratories. QAQC (QAQC: Quality Assurance/

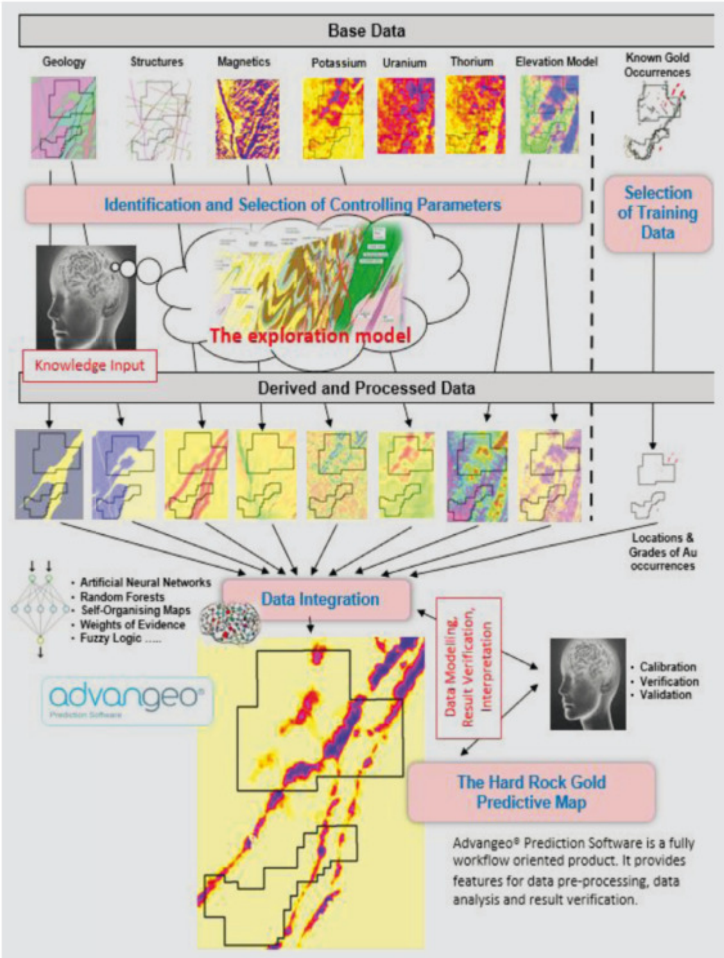

Fig. 6: ANN-based exploration targeting workflow implemented in the advangeo® Prediction Software

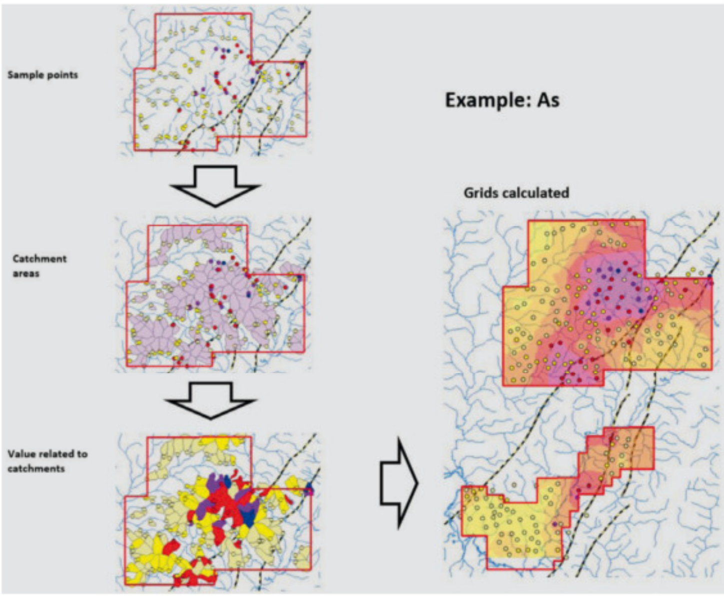

Fig. 7: Scheme of stream sediment data processing

Fig. 8: Placer exploration pitting

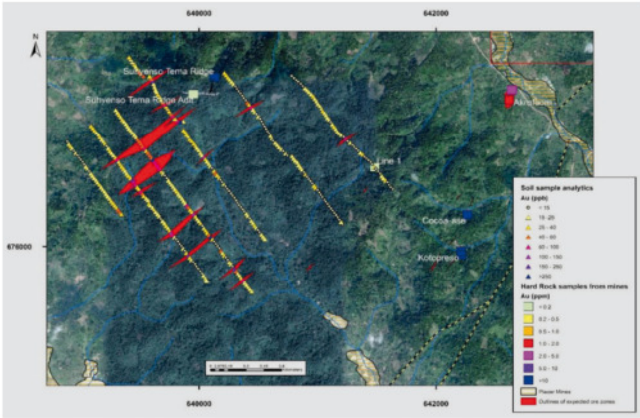

Fig. 9: Soil geochemistry lines at the Suhyenso Tema Ridge area and interpreted primary gold mineralisation zones

Fig. 10: Auger bore hole line for targeting potential hard rock mineralisation upslope of ASM slope debris mining

Fig. 11: Abandoned ASM pit on Suhyenso Tema ridge

Fig. 12: Milky smoky quartz with 41 ppm gold from the Suhyenso Tema Ridge abandoned pit waste (see Fig. 11) waste

Quality Control) was executed using blanks, duplicates and standard reference materials.

- **Placer exploration pitting** (63 pits, 1 x 1 m) was used for identification of placer resources (Fig. 8).
- **Soil sampling** was used to identify primary ore zones in stream sediment anomalies and ANN identified target zones (Fig. 9).
- **Auger drilling** (110 bore holes) was used for the verification of primary mineralization targets (Fig. 10). **Hard rock sampling** was executed for the evaluation of primary mineralisation. 87 samples have been taken from active and abandoned hard rock mining sites (Figs. 11 and 12) and from bed rock recovered in placer exploration pits.

7 The final Target Maps

The final exploration target map combines the results of four independently generated datasets:

- The stream sediment gold anomaly map
- The ANN based target map created exclusively using remote sensing data (radiometry and magnetics)
- The soil sampling results
- The hard rock sampling results

As Fig. 13 shows the results of the approaches match up very well. They have been used to identify priority follow-up areas and to design the respective programmes.

8 Results

8.1 Placer Gold

Modest gold placers are very common in the survey area. Native gold was found in almost all pits in different geomorphological positions:

- Recent valleys
- Old terraces
- Slope debris

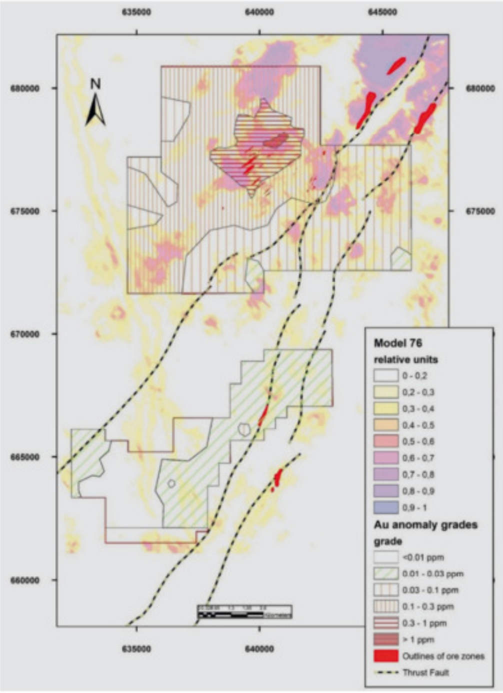

Fig. 13: The final target map: a combination of two independent datasets: stream sediment Au anomalies and ANN based targeting by remote sensing data (radiometry and magnetics)

Generally, the gold grades in the gravel do not exceed 0.2 g/m³ and in most cases are well below 0.1 g/m³. The average thickness of placers with a gold grade of > 0.04 g/m³ is 1 m, the average overburden is 0.9 m. These gold placers cover an area of 2.7 km². The value of the contained gold is just 7.8 M USD, and consequently, the value of the gold related to 1 m² of land is approx. 3 USD. The very low value of the contained gold prevents an acceptable rehabilitation of mined out areas. The placers are not recommended for mining because of the risk of significant environmental damage.

8.2 Hard Rock Gold

Hard rock gold is currently only mined by ASM operations at a few locations in the survey area. The mined material usually consists of low thickness (a few cm to a few decimetres) quartz veins in carbonaceous phyllites. The Au grades in the quartz veins are high and range from 10 to 43 g/t. Based on soil sampling data a series of ore zones of up to 100 m thickness and 1.5 km lateral extension was identified in the Tema Ridge Mountains. Because of the 2 m interval channel sampling these veinlets were not identified during earlier industrial exploration trenching programmes. Only sub-economic gold mineralisation of 0.1 – 2 g/t was identified in many trenches during the 1970s and 1980s. The high-grade quartz veins have been diluted down to uneconomic grades by low-grade host rocks. The ore zones identified at that time were too small and/or too low grade for large-scale industrial opencast mining.

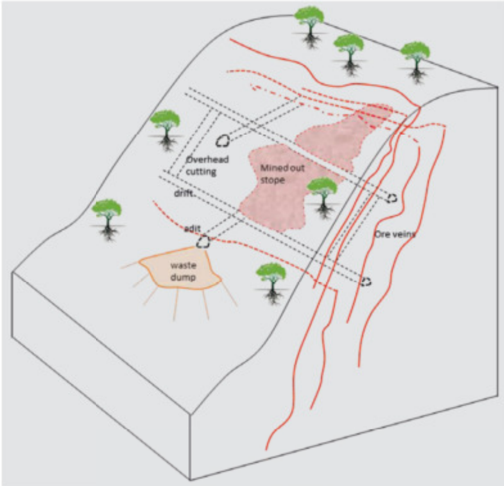

Fig. 14: The proposed mining technology consists of traditional vein mining using a system of adits, drifts, overcuttings and steep stopes.

These mineralisations now have prospects for typical vein mining by small to medium sized operations combining a system of tunnels, drifts and steep-gradient stopes (**Fig. 14**) with hand picking of the quartz material. High-grade quartz material can be processed by crushing, milling and grinding followed by gravity separation. The tailings and potentially low-grade host rock material can be leached using a simple cyanide-based process.

9 Next Steps

The potential target areas have been ranked (**Fig. 15**, **Table 1**), and follow-up work is recommended in two first and two second priority areas, including soil sampling on lines, trenching, and inclined drilling.

Exploration activities for identification of mineable resources will be combined with metallurgical investigations to identify simple and effective recovery technologies for the respective ore type: native Au in almost mono-mineral quartz veins.

Exploratory adits can be used for both detailed exploration and recovery of material for metallurgical test-work.

Table 1: Ranking matrix of target areas

Area Number	1	2	3	4	5	6	7	8
Area [km²]	15.8	6.3	8.4	3.1	6.7	0.9	9.9	2.6
Priority Status	1	1	2	2	3	4	4	4
Level of Au anomaly in stream sediments	3	2	2	2	3	4	4	4
Predictive Model #76 status	3	2	2	3	2	1	1	2
Large thrust fault in the area?	0	1	0	0	1	1	1	0
Hard rock gold ASM activities?	3	3	0	0	0	0	1	0
K anomaly?	3	3	3	3	2	2	1	2
Sum of parameters	12	11	7	8	6	5	5	5

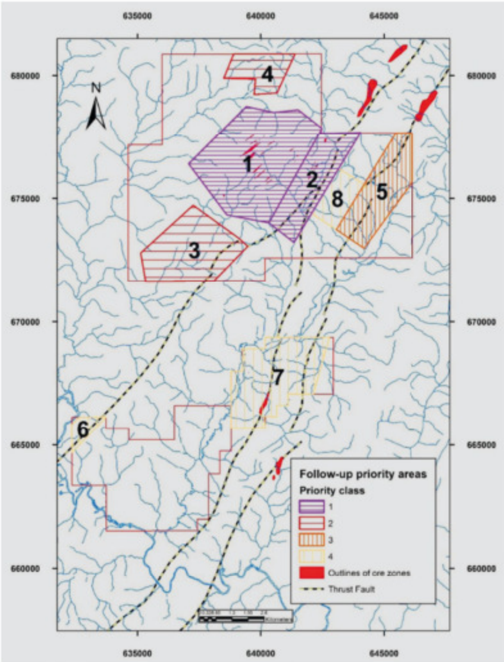

Fig. 15: Identification and ranking of potential target areas

The proposed type of small- to medium-scale underground mining requires a solid business and economic model, this to be executed by well-organised economic entities. Solid pre-financing is required to implement the necessary exploration and feasibility studies.

Economic operators could possibly form a co-operative venture involving existing large-scale mines with the new small- to medium-scale mining enterprises.

10 Conclusions

Within just six months a multi-component programme has been set up to evaluate both the placer and the hard rock gold potential within the 115 km² survey area. Placer occurrences have been evaluated as not economic, while the hard rock gold potential was recommended for further detailed exploration. The prospective mineralisation style was identified as low thickness and high-grade quartz veins hosted by phyllites.

Implementing the multistep ANN-based exploration targeting technology in combination with a streamlined field work programme proved very successful. This strategy served to minimise exploration expenditure and speed-up the target identification process. The same methodology can be recommended for further application throughout the country.

11 References

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