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Land suitability analysis for Tabriz County, Iran: a multi-criteria evaluation approach using GIS

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In our research we investigated the optimal utilization of land resources for agricultural production in Tabriz County, Iran. A GIS-based Multi Criteria Decision Making land suitability analysis was performed. Hereby, several suitability factors including soils, climatic conditions, and water availability were evaluated, based on expert knowledge from stakeholders at various levels. An Analytical Hierarchical Process was used to rank the various suitability factors and the resulting weights were used to construct the suitability map layers. In doing so, the derived weights were used, and subsequently land suitability maps for irrigated and dry-farm agriculture were created. Finally, a synthesized land suitability map was generated by combining these maps and by comparing the product with current land use SPOT 5 satellite images. The resulting suitability maps indicate the areas, in which the intensity of land use for agriculture should increase, decrease or remain unchanged. Our investigations have revealed that 65676 hectares may be suitable for irrigation and 120872 hectares may be suitable for dry-farm agriculture. This indicates a substantial potential to satisfy the significantly increasing regional demand for agricultural products. The results of our research have been provided to the regional authorities and will be used in strategic land use planning.

Keywords: land suitability analysis; GIS; GIS-Multi-Criteria Decision Making; land use/land cover; agricultural potential; Tabriz County; Iran

1. Introduction

Increasing population numbers, particularly in developing countries, intensify the pressure on both natural and agricultural resources. To meet the nutritional demands of the growing world population, an increased food supply is required. Both population increases and the process of urbanisation have increased the pressure on agricultural resources (Orhan *et al.* 2003). In many cases, especially in semi-arid regions, the limited availability of agricultural land is a critical factor. This increased pressure on the available land resources may result in land degradation (Elaalem *et al.* 2011). Reliable and accurate land evaluation is therefore indispensable to the decision-making processes involved in developing land use policies that will support sustainable rural development. If self-sufficiency in agricultural production is to be achieved in developing and transitional countries,

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land evaluation techniques will be required to develop models for predicting the land's suitability for different types of agriculture (Elaalem *et al.* 2010).

> Land suitability is the ability of a particular type of land to support a specific use, and the process of land suitability classification involves the evaluation and grouping of particular land areas in terms of their suitability for a defined use. (Prakash 2003, 2)

The main objective of this evaluation is to identify the "inherent capacity of a land unit to support a specific land use over a long period of time without deterioration, thus minimising the socio-economic and environmental costs" (Prakash 2003, 2). Land suitability is related to sustainable development (Chandio and Bin Matori 2011), which was defined by the World Commission on Environment and Development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Marrewijk 2003, 103). The results of land suitability analysis may be considered as a guide in the strategic land use decision making (Al-Mashreki *et al.* 2011b). Multi-criteria evaluation processes are already used in some regional planning processes since they aim at "estimating the potential of land for alternative land uses, among which agricultural land use may be the most important area where it is applied" (Chen *et al.* 2008, 1321). This method could play a key role in future land-use planning (Yu *et al.* 2011a).

Agricultural land suitability classification based on indigenous knowledge is vital to land use planning. The systematic assessment of land and water potential aims to identify and put into practice future alternative land uses that will best meet the needs of the people, while at the same time safeguarding resources for the future (FAO 1993). Selecting the most appropriate land evaluation technique is therefore very important for current and future land use planning in countries such as Iran. Land use policy makers in developing countries often make little use of the available technical information, and when doing so they require it to be interpreted into concise statements with few technical details (Nwer 2005, Elaalem *et al.* 2010). There are many different approaches that are widely implemented in land evaluation such as, for example, the United States Department of Agriculture (USDA) USDA land capability classification (1961) or the United Nations Food and Agriculture Organisation (FAO) framework for land evaluation (1976). Some of these techniques have been applied in developing countries, often without taking into account local knowledge and local conditions (Clayton and Dent 1993). Remote sensing and GIS techniques serve as an analytical and predicting method for planning aquacultural development and for testing the consequences of various development planning decisions (Burrough 1986, Aguilar-Manjarrez and Ross 1995, Shahadat Hossain and Gopal Das 2010). However, GIS spatial analysis is not a new concept, but rather forms an important part of land use suitability mapping and analysis (Collins *et al.* 2001, Malczewski 2004, 2006a). In general, suitability analysis aims to identify the most appropriate spatial pattern for future land uses according to the particular requirements, preferences or predictions of a particular activity (Hopkins 1977, Collins *et al.* 2001).

> GIS are best suited for handling a wide range of criteria data at multi-spatial, multi-temporal and multi-scale from different sources for a time-efficient and cost-effective analysis. (Chen *et al.* 2010b, 175)

The use of GIS Multi-Criteria Decision Making (MCDM) methods allows the user to derive knowledge from different sources, in order to support land use planning and management (Malczewski 1999a, 2004). The multi-criteria evaluation approach based on GIS decision rules (Reshmidevi *et al*. 2009, Yu *et al*. 2011a) can reduce the number of factors used in land suitability analysis. One multi-attribute technique that has been incorporated into the GIS-based land use suitability procedure is the Analytical Hierarchy Process (AHP) (Saaty 1980, Malczewski 2004). This is a two-fold approach realised within a GIS environment. First, it can be employed to derive the weights associated with suitability (attribute) map layers. The weights can then be combined with the attribute map layers in a manner similar to that used in the linear additive combination methods (Malczewski 2004). MCDM methods such as the AHP method have been successfully applied to land evaluation techniques (Parkash 2003). These methods, which aim to allow for a transparent decision-making base are, however, only rarely used in developing and transitional countries such as Iran. We have used a GIS-based MCDM land suitability analysis method to classify Tabriz County with respect to the potential for irrigated agriculture and dry-farm agriculture. We began with the hypothesis that this would be the most useful and appropriate method if the farmers' knowledge was to be incorporated into the process. We assumed that this goal could be effectively achieved through the subsequent use of GIS, as in previous studies in other parts of the world (Lawas and Luning 1996, Wandahwa and Van Ranst 1996, Zurayk *et al*. 2001, Gonzalez 2002, Cools *et al*. 2003, Oudwater and Martin 2003).

2. Case study area

The studied area was Tabriz County, which is located in the East Azerbaijan province of Iran (Figure 1). This county has an area of 2270 km^2 and is situated in

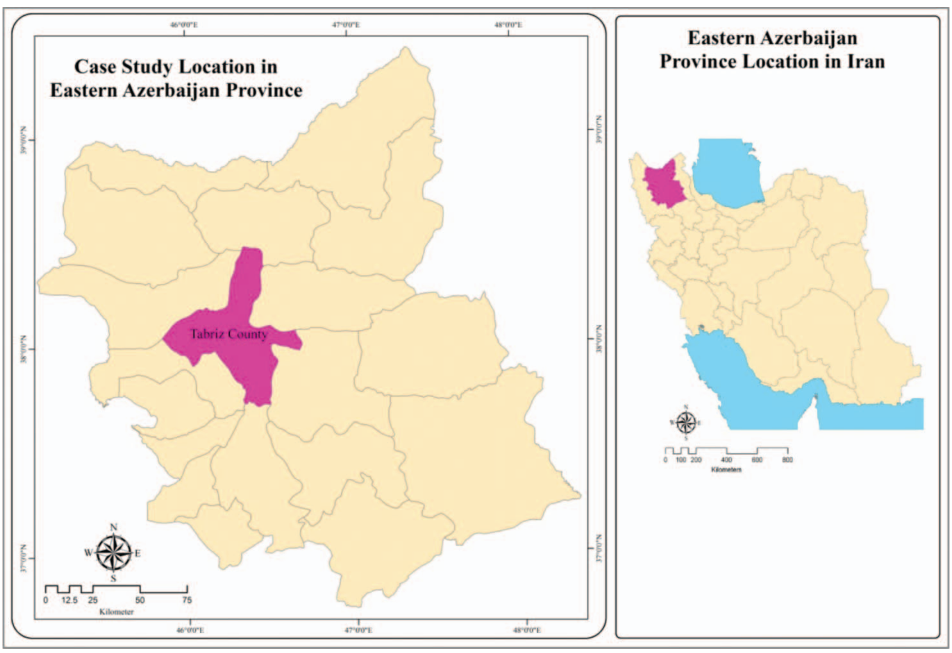

Figure 1. Location of case study area in the East Azerbaijan province (left) and Iran (right). (See online colour version for full interpretation.)

the north-western part of Iran. Four cities and 76 villages comprise an overall population of approximately 1.58 million (Iranian Census Centre 2007). Elevations range from 1320 to 3710 metres above sea level. Tabriz County contains some of the most important human habitations in the East Azerbaijan province and includes its major industrial and agricultural centres. Agriculture is one of the main sources of income for the population (Feizizadeh 2008). The agriculture is dependent on groundwater and on managed surface runoff water resources; in particular, the three major reservoirs (Malk Kian, Amand and Dash Espiran) are critical sources of water for this region. Daily temperatures range from 14 to 30°C in summer and 5 to −4°C in winter (Ministry Governorate of East Azerbaijan Province 2008). The average annual precipitation for the studied area amounts to 300 mm, most of which occurs in April and May, with approximately 100 mm falling in the winter. The studied area is characterised by different types of soil and topography that makes it suitable for a variety of land uses and different types of rural production. Dry-farming on the suitable slopes of the Sahand Mountains is one of the agricultural sources in this region (Feizizadeh *et al*. forthcoming). However, as stated previously, the increase in population is leading to an increased demand for agricultural products that cannot be satisfied by these dry-farming practices alone, even though they are relatively extensive.

3. Methodology

3.1. Multi-criteria decision making

MCDM approaches were developed in the 1960s in order to assist decision makers in incorporating numerous options, reflecting the opinions of concerned parties, into a potential or retrospective framework. This framework is ''primarily concerned with how to combine the information from several criteria to form a single index of evaluation'' (Yu *et al*. 2011a, 131). They were designed to define the relationship between data input and data output. MCDM methods can be broadly divided into either multi-objective or multi-attribute methods (Malczewski 1999a, 2004), and are primarily concerned with ways of combining several criteria to form a single evaluation index. In MCDM, each and every criterion is given a weight to represent its genuine importance in the phenomenon (Chow and Sadler 2010). Chen *et al*. (2010b) stressed the importance of recognising the conditional state of the MCDM-derived ranking weights. These are dependent on the nature of the alternatives under consideration, the criteria used to compare alternatives, and the weights derived for criteria (Al-Mashreki *et al*. 2011a). The integration of GIS and MCDM methods provides powerful spatial analysis functions (Yu *et al*. 2009). In the MCDM approach:

> GIS are best suited for handling a wide range of criteria data at multi-spatial, multi-temporal and multi-scale from different sources for a time-efficient and cost-effective analysis. Therefore, there is growing interest in incorporating GIS capability with MCDM processes. (Chen *et al*. 2010b, 175)

Due to the large number of factors involved in decision making, land suitability analysis can be identified as a multi-criteria evaluation approach (Reshmidevi *et al*. 2009, Yu *et al*. 2011b). We may conclude that spatial MCDM has thus become one of the most useful methods for land use analysis and environmental planning, as well as for agricultural land suitability classification (Davidson *et al*. 1994, Ahamed *et al*.

2000, Joerin *et al*. 2001, Ceballos Silva and Lopez Blanco 2003, Sicat *et al*. 2005, Chen *et al*. 2007, 2010b). GIS-MCDM can be thought of as "a process that transforms and combines geographical data and value judgements (the decision-maker's preferences) to obtain information for decision making" (Malczewski 2006b, 730). MCDM provides a rich collection of procedures and algorithms for structuring decisional problems and for designing, evaluating and prioritising alternative decisions. It is in the context of the synergetic capabilities of GIS and MCDM that one can observe the benefits for advancing theoretical and applied research on the integration of GIS and MCDM (Malczewski 1999a, 2006b, Boroushaki and Malczewski 2010). Of the various MCDM methods, the Analytical Hierarchy Process is a well-known multi-criteria technique that has been incorporated into GIS-based suitability procedures (Jankowski and Richard 1994, Marinoni 2004). The AHP is a method widely used in MCDM to obtain the required weightings for different criteria (Saaty 1977, 1980, Saaty and Vargas 1991, Wu 1998, Ohta *et al*. 2007). It has been successfully employed in GIS-based MCDM since the early 1990s (Carver 1991, Malczewski 1999a, 1999b, 2004, Makropoulos *et al*. 2003, Marinoni 2004, Marinoni *et al*. 2009). The AHP method calculates the required weights associated with the respective criterion map layers with the help of a preference matrix, in which all relevant criteria identified are compared against each other on the basis of preference factors. The weights can then be aggregated. GIS-based AHP has gained popularity because of its capacity to integrate a large quantity of heterogeneous data, and because obtaining the required weights can be relatively straightforward, even for a large number of criteria. It has been applied to a variety of decision-making problems (Tiwari *et al*. 1999, Nekhay *et al*. 2008, Hossain and Das 2010, Chen *et al*. 2010b). For the classification of land suitability within our case study area in northern Iran, we utilised the AHP's ability to incorporate different types of input data, and the pairwise comparison method for comparing two parameters simultaneously. The application of AHP process involves the following steps (Elaalem *et al*. 2011):

- Criteria or factors contributing to the set of suitable are identified;
- The relative importance of each factor to each other factor, i.e. between pairs of criteria. This is usually done by domain and experts' opinions;
- The consistency of the overall set of pairwise comparisons is assessed using its Consistency Ratio (CR).

3.2. Selection of evaluation criteria

Evaluation criteria objectives and attributes need to be identified with respect to the particular situation under consideration. The set of criteria selected should adequately represent the decision-making environment and contribute towards the final goal (Prakash 2003). "Land suitability assessment is a multiple criteria evaluation process. The attributes of land suitability criteria are to be derived from spatial and non-spatial, qualitative and quantitative information under diverse conditions" (Chen *et al*. 2010a, 175). In land suitability analysis, each evaluation criterion is represented by a separate map in which a 'degree of suitability' with respect to that particular criterion is ascribed to each unit of area (Sehgal 1996, Prakash, 2003). These 'degrees of suitability' then need to be rated according to the relative importance of the contribution made by that particular criterion, towards achieving the ultimate objective. In this study, four main criteria, namely: topography, climate, soil properties and water resources for irrigation, were selected based on local expert knowledge. Next, eight causal factors, including: elevation, slope, aspect, soil fertility, soil PH, temperature, precipitation and groundwater, were selected. The casual factors were chosen based on the four main criteria but also under consideration of literature inputs and data availability (Ayalew and Yamagishi 2005). In comparable studies, all four criteria are often used for susceptibility mapping (Ahamed *et al*. 2000, Prakash 2003, Malczewski 2004, Ranjbar 2007, Reshmidevi *et al*. 2009, Akmal Rahim *et al*. 2010, Chen *et al*. 2010a, 2010b, Hossain and Das 2010, Jafari and Zaredar 2010, Jei *et al*. 2010, Shahadat Hossain and Gopal Das 2010). The evaluation criteria are listed in Table 1.

3.3. Data collection and preparation using GIS

Data preparation is the first fundamental step in land suitability analysis. Our methodology is based on GIS analysis. In our methodology, land suitability is evaluated by applying different GIS analytical techniques, including interpolation and overlay based on multi-criteria analysis and AHP. For this to happen, the following datasets were prepared:

- Soil maps 1:50000 (Ministry of Agriculture in East Azerbaijan province) are used to derive the soil PH value and soil fertility.
- Digital topographical maps 1:25000 (National Cartographic Centre organisation) are used to create TINs, DEM, and derivate layers such as slope and aspect.
- Two SPOT 5 satellite images with 10 m spatial resolution were used to derive land use / land cover through image classification techniques.
- Meteorological data for a 30-year period (Iranian Meteorology Organisation) were used to create climate maps including: precipitation and temperature.

After these spatial datasets were prepared, including all necessary geometric and thematic editing of the original datasets, a topology was created. All vector layers were then converted into raster format with 10 m resolution and the spatial datasets were processed in ArcGIS. Slope and aspect were generated from a 10 m resolution DEM which was derived from 1:25000 topographical maps. The spatial distributions of some of the most important import datasets like the DEM and some of the derived datasets are shown in Figures 2 and 3.

Table 1. General criteria (left column) and criteria/factors used in the study (right column).

Topography	Elevation
	Slope
	Aspect
Soil	Fertility
	PH
Climate	Temperature
	Precipitation
Irrigation	Groundwater

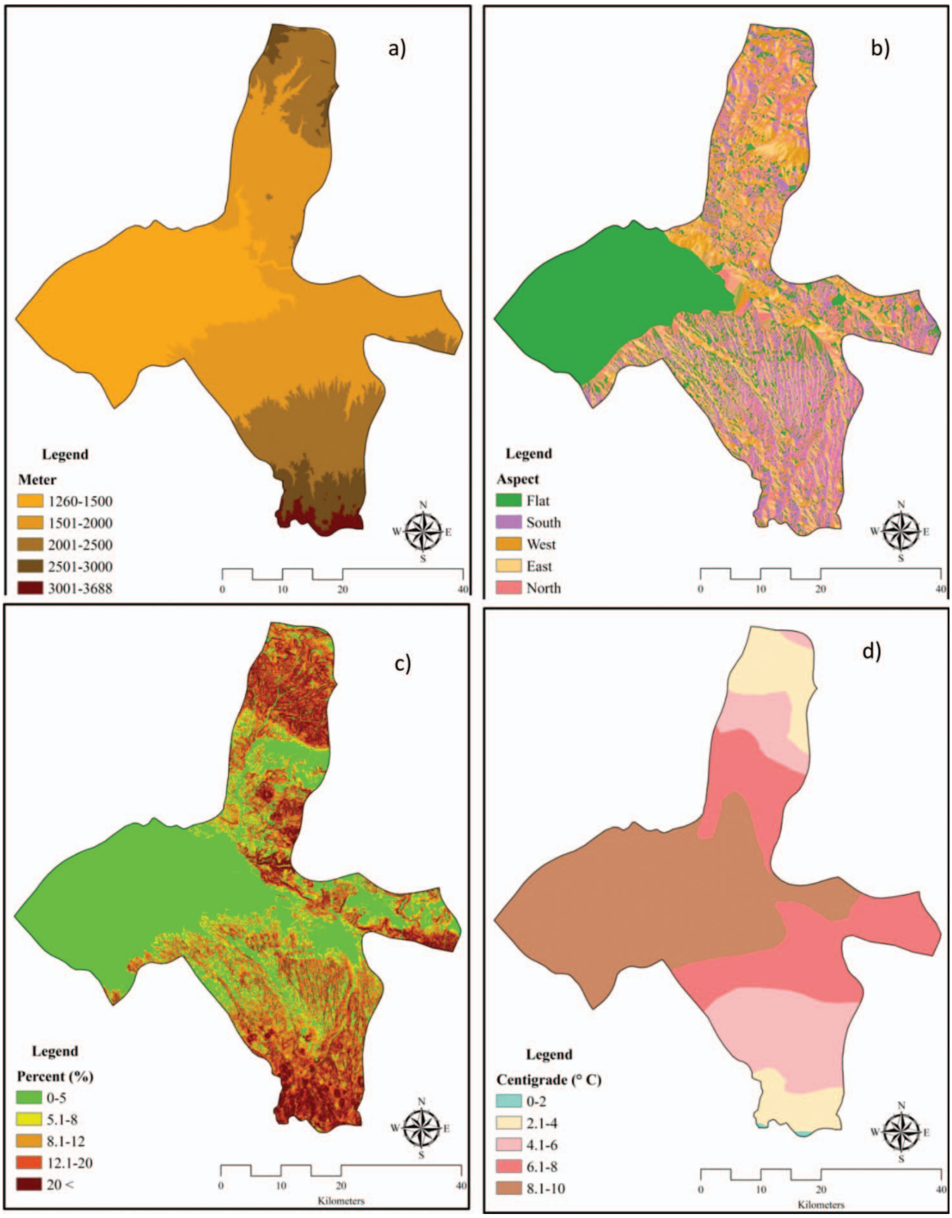

Figure 2. Physiography of the study area (a) elevation; (b) slope aspect; (c) slope range; (d) annual average temperature. (See online colour version for full interpretation.)

3.4. Standardisation of criteria

The process of setting the relative importance of each criterion is known as the standardisation of criteria (Prakash 2003). In this process scales of 0 to 1, 0 to 10 or 0 to 100 (etc.) are normally used for criteria standardisation. A pairwise comparison technique is typically used for rating and standardising the ordinal values (Malczewski 2004). This technique is an extension of the classic binary logic, with the possibility of defining sets without sharp boundaries and allowing for partial

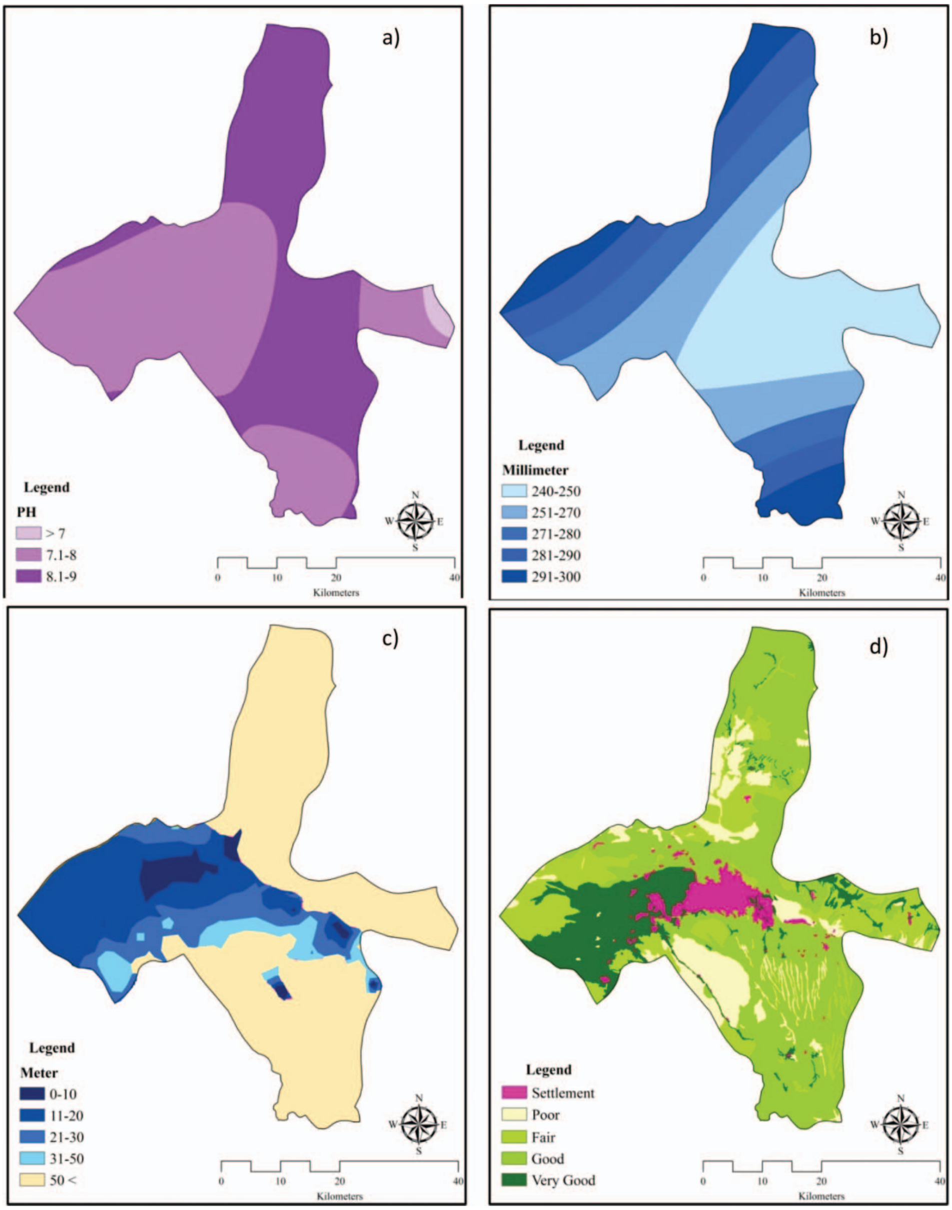

Figure 3. Criteria spatial distributions of the study area (a) soil PH; (b) annual precipitation; (c) groundwater depth; (d) soil fertility. (See online colour version for full interpretation.)

assignation of elements to a particular set. A fuzzy set is essentially a set whose members may have degrees of membership between 0 and 1, as opposed to a classic binary set in which each element must have either the value 0 or 1 as their membership degree (Malczewski 2004). In this particular land suitability analysis for northern Iran' the criteria are represented by GIS dataset layers. These criteria at the lowest level, and the resulting memberships of different suitability classes, were subsequently standardised using the maximum Eigenvectors approach on a 0 to 1 scale.

3.5. Assessing the weights: obtaining decision rules through AHP

Criterion weights are the weights assigned to the objective and attribute maps (Meng *et al*. 2011). Deriving weights for the selected map criteria (land characteristics map layers) is a fundamental requirement for applying the AHP method (Malczewski 1999a, 2004). The determination of the particular criterion weight is therefore a crucial step in MCDM. As previously discussed, the AHP is considered to be an adequate mathematical method for this step when analysing complex decisional problems (Saaty 1977, 1980, Malczewski 2004). It derives the weights by comparing the relative importance of the criteria in a pairwise manner. Through a pairwise comparison matrix, the AHP calculates the weighting for each criterion (wi) by taking the Eigenvector corresponding to the largest Eigenvalue of the matrix, and then normalising the sum of the components to unity as:

$$\sum_{i=1}^{n} wi = 1. \tag{1}$$

The overall importance of each of the individual criteria is then calculated. An importance scale is proposed for these comparisons (Table 2). The basic input is the pairwise comparison matrix, A, of n criteria, established on the basis of Saaty's scaling ratios, which is of the order (n × n) as defined in equation (2) below (Chen *et al*., 2010b):

$$A = [aij], i, j = 1, 2, 3, \ldots, n \tag{2}$$

in which A is a matrix with elements a*ij*. The matrix generally has the property of reciprocity, expressed mathematically as:

$$aij = 1/aji. \tag{3}$$

After generating this matrix it is then normalised as a matrix B:

$$B = [bij], i, j = 1, 2, 3, \ldots, n. \tag{4}$$

in which B is the normalised matrix of A, with elements bij defined as:

$$bij = \frac{aij}{\sum_{i=1}^{n} aij = 1, 2, 3, \cdots, n}. \tag{5}$$

Table 2. Scales for pairwise AHP comparisons.

Intensity of importance	Description
1	Equal importance
3	Moderate importance
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
Reciprocals	Values for inverse comparison

Source: (Saaty and Vargas 1991).

Each weight value w_i is computed as:

$$\text{wi} = \frac{\sum_{j=1}^{n} bij}{\sum_{i=1}^{n}\sum_{j=1}^{n} bij}, i, j = 1, 2, 3, \cdots, n. \tag{6}$$

Equations (7) to (9) represent the relationships between the largest Eigenvalue (λmax) and corresponding Eigenvector (W) of the matrix B (Xu 2002, Chen *et al.* 2010b):

$$\text{BW} = \lambda\text{maxW}. \tag{7}$$

In our study of the implementation of the pairwise comparison matrix, experts' opinions were asked to calculate the relative importance of the factors and criteria involved. The calculated pairwise comparison matrixes for irrigation and dry-farming suitability within the case study area are shown in Tables 3 and 4; in addition, the details of the weights used for the evaluation criteria are listed in Tables 5 and 6.

In the application of the AHP method it is important that the weights derived from a pairwise comparison matrix are consistent. Therefore, one of the strengths of AHP is that it allows for inconsistent relationships while, at the same time, providing a consistency ratio (CR) as an indicator of the degree of consistency or inconsistency (Forman and Selly 2001, Chen *et al.* 2010b). The CR is used to indicate the likelihood that the matrix judgements were generated randomly (Saaty 1977, Park *et al.* 2011).

$$CR = \frac{CI}{RI}. \tag{8}$$

Hereby the random index (RI) is the average of the resulting consistency index, depending on the order of the matrix given by Saaty (1977), and the consistency index (CI) can be expressed as:

$$CI = \frac{(\lambda_{\max} - n)}{n - 1} \tag{9}$$

in which λ max is the largest or principal Eigenvalue of the matrix, and n is the order of the matrix. A consistency ratio (CR) of 0.10 or less indicates a reasonable level of consistency (Saaty 1977, Park *et al.* 2011). The determination of the CR value is critical. The CR has been widely used as a measure of the consistency in a set of judgements of AHP applications in literature (Chen *et al.* 2010b). If the CR $<$ 0.10, it deems that the pairwise comparison matrix has an acceptable consistency and that the weight values calculated in equation (6) are valid and can be utilised. Otherwise, if the CR $\geq$ 0.10 it means that the pairwise comparisons are lacking consistency, in other words the matrix needs to be adjusted and the element values should be modified (Bodin and Gass 2003, Chen *et al.* 2010b). In our study, the resulting CR for the pairwise comparison matrix for irrigation suitability was 0.04 and 0.05 for dry-farm suitability, respectively. This indicates that the comparisons of land characteristics were perfectly consistent and that the relative weights were appropriately chosen in this particular land suitability evaluation model.

Table 3. AHP pairwise comparison matrix for irrigated agriculture.

Land characteristics	Aspect	Precipitation	PH	Slope	Elevation	Fertility	Temperature	Irrigation	Eigen values
Aspect	1								0.0214
Precipitation	2	1							0.0308
PH	3	1	1						0.0356
Slope	4	3	3	1					0.0747
Elevation	5	4	3	1					0.0877
Fertility	6	5	2	1	1				0.1136
Temperature	7	6	6	3	3	2	1		0.1823
Irrigation	9	9	8	7	7	5	5	1	0.4539

Table 4. AHP pairwise comparison matrix for dry-farming agriculture.

Land characteristics	Elevation	PH	Slope	Aspect	Temperature	Fertility	Precipitation	Eigen values
Elevation	1							0.0342
PH	2	1						0.0328
Slope	3	2	1					0.0481
Aspect	5	3	2	1				0.0742
Temperature	6	5	4	3	1			0.1415
Fertility	7	7	6	5	3	1		0.2538
Precipitation	9	9	8	7	5	2	1	0.4154

Table 5. Detailed weights and ranges for the criteria for irrigated agriculture.

Main criterion	Criterion	Weight	Detailed weights for ranges of criteria between 1–5 (5 equal to very important and 1 equal to less important)				
Irrigation	Groundwater (m)	0.4539	0–10 5	11–20 4	21–30 3	31–50 2	50 < 1
Topography	Elevation (m)	0.0877	1261–1500 5	1501–2000 4	2001–2500 3	2500–3000 2	3000–3668 1
	Slope (%)	0.0747	0–5 5	5.1–8 4	8.1–12 3	12.1–20 2	20 < 1
	Aspect	0.0214	Flat 5	North 4	West 3	East 3	South 2
Soil	Fertility	0.1136	Very good 5	Good 4	Fair 3	Poor 2	– –
	PH	0.0356	7 < 5	7.1–8 4	8.1–9 3	– –	– –
Climate	Temperature (° C)	0.1823	0–2 1	2.1–4 2	4.1–6 3	6.1–8 4	8.1–10 5
	Precipitation (mm)	0.0308	240–250 1	251–270 2	271–280 3	281–290 4	291–300 5

Table 6. Detailed weights and ranges for the criteria for dry-farm agriculture.

Main criterion	Criterion	Weight	Detailed weights for ranges of criteria between 1–5 (5 equal to very important and 1 equal to less important)				
Topography	Elevation (m)	0.0342	1261–1500	1501–2000	2001–2500	2500–3000	3000–3668
			5	4	3	2	1
	Slope (%)	0.0481	0–5	5.1–8	8.1–12	12.1–20	20 <
			3	4	5	2	1
	Aspect	0.0742	Flat	North	West	East	South
			5	4	3	3	2
Soil	Fertility	0.2538	Very good	Good	Fair	Poor	–
			5	4	3	2	–
	PH	0.0328	7 <	7.1–8	8.1–9	–	–
			5	4	3	–	–
Climate	Temperature (°C)	0.1415	0–2	2.1–4	4.1–6	6.1–8	8.1–10
			1	2	3	4	5
	Precipitation (mm)	0.4154	240–250	251–270	271–280	281–290	291–300
			1	2	3	4	5

3.6. *Overlaying map layers*

The integration of MCDM techniques with GIS has allowed considerable advances to be made over conventional map overlay approaches for land use suitability analyses (Carver 1991, Malczewski 1999a). The MCDM procedures (or decision rules) define a relationship between the input maps and the output map. The procedures involve the utilisation of geographical data, the decision-maker's preferences, and the manipulation of the data and preferences according to specified decision rules (Malczewski 1999a). Weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input data to create an integrated analysis (Kuria *et al*. 2011). In this study, different map layers characterising land suitability have been weighted using the weights derived from the AHP process described in previous section. The weights were then combined with the attribute map layers in a manner similar to that used in the linear additive combination methods (Malczewski 2004, Feizizadeh and Blaschke 2011). The results are displayed in (Tables 5 and 6). The maps resulting from this weighted overlay, for both irrigation suitability and dry-farm suitability, are shown in Figures 4a and 4b. After the weighted overlay and the following extraction of both irrigation and dry-farm suitability maps, a final land suitability map of Tabriz county was derived. The final land suitability map is based on the best outcome in context of the suitability of agricultural lands to produce crop yield for irrigation and dry-farm agriculture lands in crop yield and suitability for irrigation and dry-farm agriculture, respectively (Figure 4c). The final land suitability map classifies the case study area into six land suitability classes, namely: 'highly suitable for irrigation'; 'moderately suitable for irrigation'; 'highly suitable for dry-farming'; 'moderately suitable for dry-farming'; 'marginally suitable for dry-farming'; and 'unsuitable for agriculture'.

3.7. *Comparative land use map derived from satellite images*

Remotely sensed data from earth observation sensor systems is widely used in a range of oceanographic, terrestrial and atmospheric applications, including land cover mapping or environmental modelling and monitoring, as well as for updating geographical databases. Remote sensing methods and techniques have proved to be very useful for these applications (El-Raey *et al*. 1996, Kushwaha *et al*. 1996, Downie *et al*. 1999). However, remote sensing imagery needs to be converted from raw data into tangible information that can be utilised in conjunction with other datasets, for example, within Geographic Information Systems (Blaschke 2010).

As part of our investigations we produced a current land use/cover classification for the case study area in order to compare the results of the MCE land suitability analysis with the current land use. For this purpose we used two SPOT 5 satellite scenes with a spatial resolution of 10 m from 27 May 2005 for a supervised classification. After geo-referencing and atmospheric correction, the images were classified using a maximum likelihood classification (MLC) algorithm in a per-pixel classification approach. As it is widely known (Blaschke 2010, Weng, 2010), the pixel-based image classification approach classifies remote sensing images according to the spectral information in the image in a 'pixel by pixel' manner. For the vast majority of methods, which use unsupervised and supervised classification techniques (Yan 2003, Seetha *et al*. 2005, Weng 2010), each pixel can only belong to a single class. Supervised classifications are generally more closely controlled by the user than unsupervised classifications. In this process, pixels that form patterns

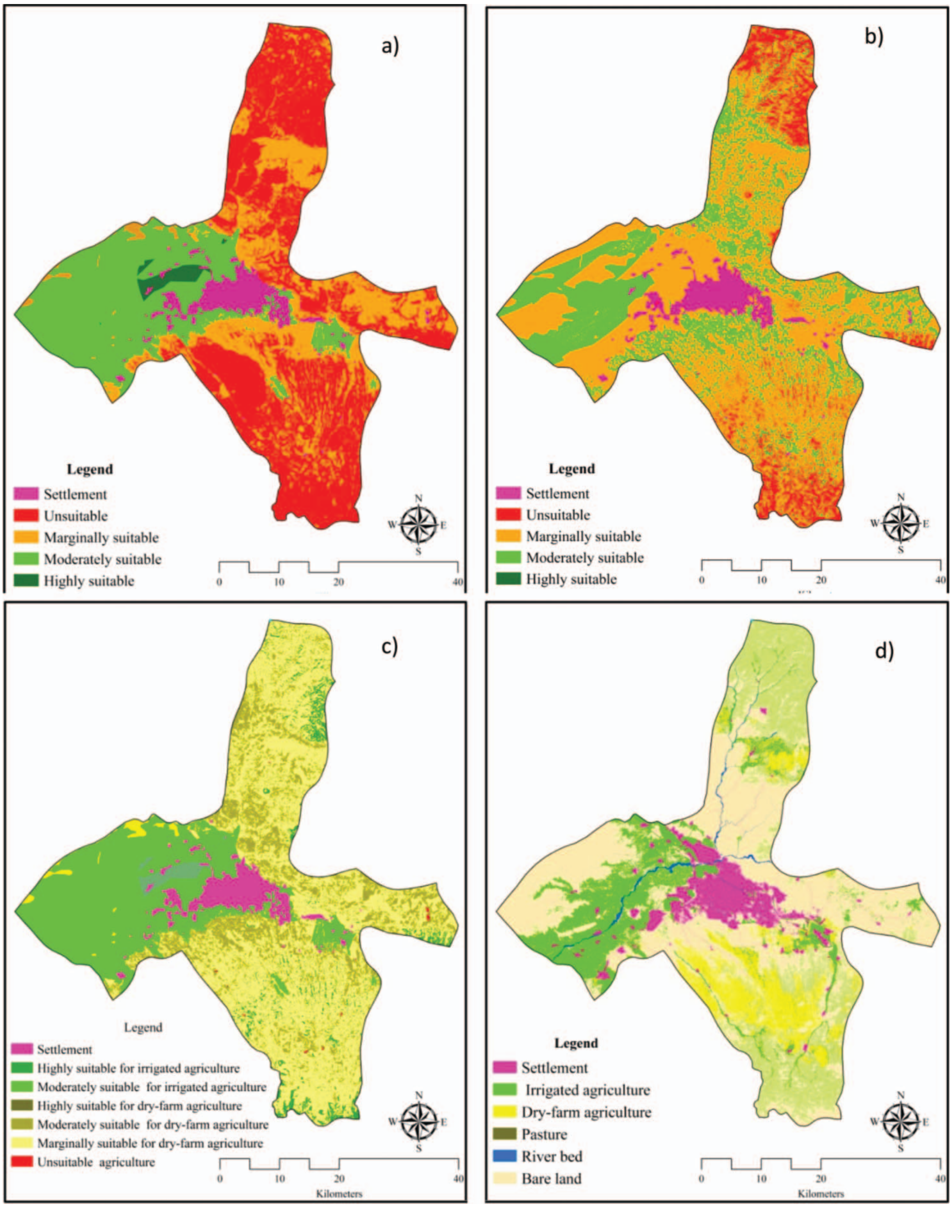

Figure 4. Land suitability and land use/ cover maps of the study area (a) suitability map of irrigated agriculture lands; (b) dry-farming agriculture land suitability map; (c) final land suitability map; (d) land use/cover classification map. (See online colour version for full interpretation.)

which are recognised by the user are selected as well as patterns identified from other sources. Prior to the selection of training samples, knowledge of the data, the classes desired and the algorithm are assimilated. There are three basic stages involved in the supervised classification method: a training stage, a classification stage, and an accuracy assessment stage. The maximum likelihood classification is based on a normalised (Gaussian) estimate of the probable density function for each class. The maximum likelihood classification quantitatively evaluates both the variance and covariance of the category's spectral response patterns, while classifying an unknown pixel (Seetha *et al*. 2005, Feizizadeh and Helali 2010). In order to evaluate the classification results for the satellite imagery, the overall accuracy and Kappa coefficient were calculated: the overall accuracy was 88.37% and the Kappa coefficient was 0.87. In a consecutive stage a land use/cover map (Figure 4d) is transferred into GIS to compare the results of the land suitability analysis with current land use/cover. In the GIS environment, a geo-database was created by calculating the geometric characteristics of each land use/cover class: the final results are presented in Table 9.

4. Results

Land suitability maps for both irrigated and dry-farm agriculture (Figures 4a and 4b) have been extracted using weighted overlay techniques. As described in the previous section, this is based on standard weights which were derived from the AHP process. The total resulting areas for both forms of agriculture reveal the importance of agriculture in Tabriz County, and the suitability of the terrain.

The map for irrigated agriculture (Figure 4a) shows that 3.28% of the investigated area is highly suitable, 39.05% is moderately suitable, 7.15% is marginally suitable, and 50.52% is unsuitable. Together, the two categories 'highly suitable' and 'moderately suitable' make up 42.33% of the total area. Geographically, these areas cover what is

Table 7. Resulting overall areas for different suitability classes: irrigated agriculture.

Land suitability class	Area (hectares)
Highly suitable	7468
Moderately suitable	88,654
Marginally suitable	100,028
Unsuitable	16,243
Total	212,393

Table 8. Resulting overall areas for different suitability classes: dry-farm agriculture.

Land suitability class	Area (hectares)
Highly suitable	11
Moderately suitable	94,126
Marginally suitable	117,395
Unsuitable	861
Total	212,393

Table 9. Current land use classes in Tabriz County.

Land suitability class	Area (hectares)
Irrigated agriculture (crop lands and orchards)	40,300
Dry-farm	26,468
Pasture	67,252
Settlement	18,797
Bare land	74,195
Total	227,012

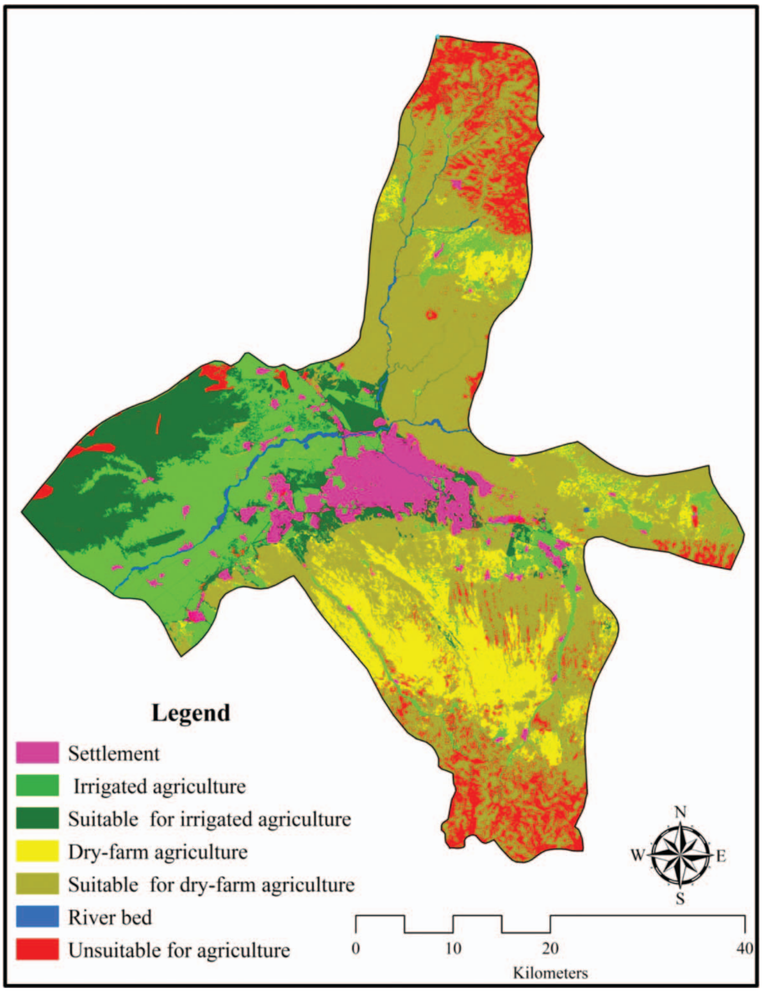

Figure 5. Present agricultural land use and potential suitability of agriculture lands. (See online colour version for full interpretation.)

already known to be the best agricultural area in Tabriz County, known as the Tabriz Plain, to the east of Lake Urmia. This area is characterised by a suitably sloping topography, productive soils and an existing irrigation network that includes canals from the Malk Kian, Amnd and Dash Espiran dams. It also includes groundwater resources that are very important for agriculture, which even supply other counties adjacent to Tabriz within the East Azerbaijan province. The Tabriz Plain area is known for its orchards and for agricultural crops such as wheat, onions, potatoes and tomatoes.

The dry-farm agriculture land suitability map (Figure 4b) reveals that very little (0.01%) of the agricultural land in Tabriz County is 'highly suitable for dry-farming', 40.33% is 'moderately suitable', 49.12% is 'marginally suitable', and 10.54% is 'unsuitable'. The 'moderately suitable' and 'marginally suitable' classes are located predominantly on the slopes of the Sahand Mountains that have suitable gradients and suitable climatic conditions, i.e. high precipitation rates during the months of May and June. High precipitation in May and June is important for the yield of dry-farming crops such as wheat (Feizizadeh *et al.* forthcoming), and is related to meso- and micro-climate factors caused by the topography and, in particular, the westerly winds that occur during May and June. These winds, originating from the Mediterranean Sea, are an important source of precipitation in northern Iran where the Sahand Mountains act as a climatic barrier and cause convectional processes on the previously mentioned slopes. In addition, the so-called Edafiki processes increase precipitation (Alijane 2000). Within a generally dry area the Sahand Mountain slopes are therefore relatively suitable for dry-farming.

5. Discussion

Land suitability has been extracted by weighted overlay techniques based on MCDM using GIS methods, a process that has resulted in information being portrayed on three land suitability maps. The results have clearly indicated in which areas in Tabriz County the intensity of land use for agriculture should increase, decrease or remain unchanged. The respective areas indicated as being suitable for irrigated and dry-farm agriculture within the case study area are shown in Tables 7 and 8. The land suitability maps have been compared with a map of current land use derived from satellite remote sensing images (see Figure 4d). Table 9 depicts the area of predominant land use. According to the land use map, 29.41% of the case study area is currently being used for agriculture, which includes 17.75% being used under irrigation and 11.66% being used for dry-farming. An additional 29.62% of the area is being used as pasture, another 32.69% of the area is classified as bare lands, and 8.28% of the area is used for settlements.

A cross-comparison between the current land use map and the land suitability map shows that the vast majority of land classified as 'highly suitable for irrigated agriculture' (7468.68 hectares) is already being used for irrigated agriculture. Meanwhile, under the classification of 'moderately suitable for irrigated agriculture' there is potential for another 65,676 hectares to be developed into irrigated agricultural land. Currently the 4780 hectares which are classified as 'moderately suitable' for irrigation are being used for dry-farming, while 43,864 hectares are classified as bare land and 17,032 hectares fall into the category of pasture: all of these classes are potentially suitable for irrigated agriculture.

In the case of dry-farm agriculture, only 11 hectares have been classified as 'highly suitable for dry-farming', all of which are already being used for dry-farming. In the context of 'moderately suitable for dry-farming' (94126 hectares) results indicated overwhelming majority of currently dry-farming areas (19619 hectares) fall within areas categorized as 'moderately suitable for dry-farming'. Meanwhile about 10116 hectares of currently under pasture and 110756 hectares of the bare lands (totalling 120,872 hectares) are potentially suitable for dry-farm agriculture.

The areas currently being used for agriculture, together with those potentially suitable for irrigated and dry-farm agriculture, are shown in Figure 5.

6. Conclusions

Land suitability maps for irrigated and dry-farm agriculture in Tabriz County were extracted using GIS-assisted MCDM analysis. These were then compared to a current land use map of the case study area, derived from SPOT 5 satellite images through image processing techniques. The results demonstrate that the areas that are classified as 'highly suitable' for irrigated and dry-farm agriculture are already largely under cultivation. However, areas classified as 'moderately suitable' are currently only being marginally used. This indicates a high potential for the further development of agricultural cultivation, for both irrigated and dry-farm agriculture. Although some parts of these areas are presently under cultivation, there remain some 65,676 hectares that are potentially suitable for development as irrigated agricultural land and 120,872 hectares that are potentially suitable for dry-farm agriculture. This information is of great importance to decision makers and, in particular, to government departments such as the Ministry of Agriculture, the Ministry of Water Resource Management, and the Ministry of Natural Resources for the East Azerbaijan Province of Iran. Following the receipt of this information by these ministries, a discussion was triggered on how to further enhance the detail of the information portrayed in the land suitability maps. This enhancement will be carried out for Tabriz County in collaboration with the decision-making authorities. It will include actions to explicitly designate areas in which the intensity of agricultural land use should increase, decrease or remain unchanged. However, in cultural landscapes the "ecological and socio-economic realms are intricately linked" (Blaschke 2006, 201). We therefore require concepts to predict and to manage future land use, but we are only just beginning to parameterise issues related to the new economy, changing lifestyles and different priorities for land use. This study is a first step that lays the foundation for a transparent regional land use policy, drawing on a comprehensive GIS database that will require regular updating. Several relevant publications already exist in the Persian language and are widely acknowledged, particularly recognising the fact that they provide transparent and reliable planning documents, based on comprehensible and replicable physical conditions, and the relative importance assigned to them by local stakeholders.

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