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C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

Using DEM and GIS for evaluation of groundwater resources in relation to landforms in the Maharlou-Bakhtegan watershed, Fars province, Iran

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Abstract

The study of groundwater resources in relation to topography is important. Clearly, in different topography, depth of the water level is different. Therefore, the aim of this study is the determination of the relationship between landform classes with compound topographic index (*CTI*) and depth of the water for the Maharlou-Bakhtegan watershed, Fars Province, Iran. In order to evaluate the depth of the water for the study area, *CTI* and geomorphology (landforms) were derived from a Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM). The results of landform classes extracted using topographic position index (*TPI*) showed that the largest landform is open slope, while the smallest are plains. It was found that *CTI* and depth of the water values are high in plain classes, while they are low in local ridges. High depth of the water were found to be mostly confined to the pit regions in the plain landform, because groundwater recharge occurs in the zones where standing water remains for sufficient long period of time and has favourable condition for recharge.

Key words: *compound topographic index (CTI), digital elevation model (DEM), geographic information system (GIS), groundwater, landforms, Maharlou-Bakhtegan, topographic position index (TPI)*

INTRODUCTION

In semi-arid environments, most land use depends on water harvested from the upper part of soil to support crops on the lower members. The entire process of water movement depends largely on the elevation of the area (derived terrain parameters), which goes into the process of characterizing the landforms [HALDAR *et al.* 2011]. The relationship for hydrogeomorphology, soil and groundwater prospects is established by KRISHNA *et al.* [2000] for ecological-economic zoning in Andhra Pradesh. They reported that groundwater occurrence is influenced by the climate, physiography, drainage and geology of the area. Delta, transitional and flood plains are reported to have very good groundwater potential, followed by

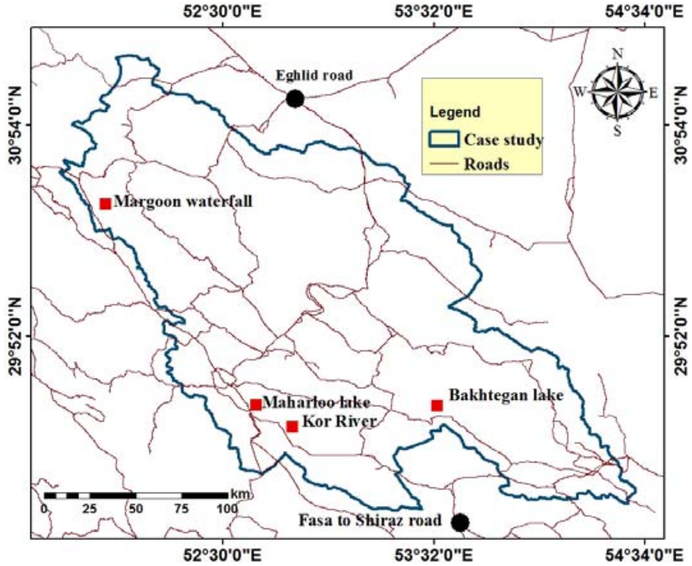

Fig. 1. Location and Shuttle Radar Topography Mission digital elevation model of the study area; source: own elaboration

pedi-plains, bajadas and pediments, while hills and inselbergs have no prospects of groundwater.

SINGH *et al.* [1983] reported that despite the significant efforts made to develop India's water resources, optimum benefit could not be attained. The depth of the groundwater in the delta was reported to be mostly shallow, and of moderate depth in the transitional plains and along filled valleys. Evaluation of groundwater and land resources in relation to landforms in the Alwar district (Rajasthan) using remote sensing was studied by HALDAR *et al.* [2011]. The results showed that high potential areas occur in plains and transitional landforms, while poor potential areas occur in hilly landforms.

CONDON and MAXWELL [2015] and CASSANELLI and HEAD [2016] investigated the relationship between meltwater generation, groundwater recharge, and resulting landforms. The results showed that there were relationships between topography and hydrology characteristics.

Watershed-based resource management organizations around the world are becoming more involved in groundwater management. This reflects, among other considerations, growing awareness of the critical role that these local agencies can and should play in the management of groundwater resources [IVEY *et al.* 2002].

SHIRAZI *et al.* [2015] investigated the groundwater quality and hydrogeological characteristics of Malacca state in Malaysia. The results show that the groundwater potential of the study area is 35, 57 and 8% of low, moderate and high class respectively.

BENRABAH *et al.* [2016] investigated characterization of groundwater quality destined for drinking water supply of Khenchela city. The results show that agricultural area was considered to be compulsory.

Therefore, by review the different authors identified an important relation between groundwater resources and topography. The aim of the study area is the evaluation of groundwater and land resources in relation to landforms in the Maharlou-Bakhtegan watershed, Fars province, Iran using remote sensing and geographical information systems (GIS). In the study area, population growth rate (0.86% per year) has led to labour requisition growth and increase in domestic, industrial and agricultural water demand. Therefore, extra water withdrawal from water resources is expected [RASI NEZAMI *et al.* 2013]. Therefore, the investigation of groundwater and its relationship with the topography of the study area is important.

MATERIAL AND METHODS

STUDY AREA

The study region has an area of about 31,491 km^2 and is located at longitude of N 29°06' to 31°14' and latitude of E 51°42' to 54°30' (Fig. 1). The altitude of the study area ranges from of 1,444 m to of 3,884 m a.s.l. The Maharlou-Bakhtegan watershed is drained mainly by the Kor River, with the main part located between Doroudzan dam and Bakhtegan Lake. The total amount of surface and groundwater flowing into the catchment is about 3521.4 million m^3. Groundwater resources supply 79% of the total water needs in the catchment [RASI NEZAMI *et al*. 2013].

GROUNDWATER INVESTIGATIONS/DATA

In the study area, 663 water points were sampled (Fig. 2) regarding depth of the water (Fars Regional Water Authority). According to Table 1, the maximum and minimum values of depth of the water is 4 and 69 m.

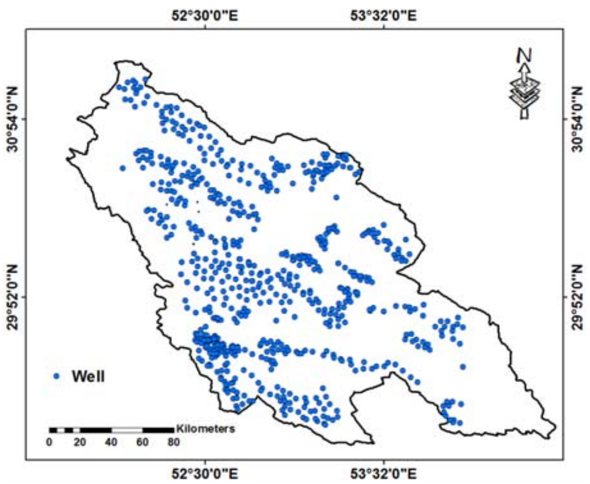

Fig. 2. Positions of log wells in the study area; source: own elaboration

Table 1. Statistic characteristics of groundwater level for 663 wells

Parameter	Value, m
Max	69.90
Min	4.00
Average	43.52
Standard deviation	12.92
Range	65.90

Source: own study.

INVERSE DISTANCE WEIGHTING (IDW)

Groundwater data in the form of well logs was used in this study to be compared with the landform map. The data was obtained from the Agriculture Organization of Fars Province (http://www.fars-agrijahad.ir). The positions of the wells are shown in Figure 2.

Inverse distance weighting (IDW) was used for interpolating groundwater depth in the study area from the wells logs. IDW assumes that the value of an attribute z at any unsampled point is a distance-weighted average of sampled points lying within a defined neighbourhood around that unsampled point. Essentially it is a weighted moving average [BURROUGH *et al.* 1998]:

$$\hat{z}(x_0) = \frac{\sum_{i=1}^{n} z(x_i) d_{ij}^{-r}}{\sum_{i=1}^{n} d_{ij}^{-r}} \qquad (1)$$

Where: $\hat{z}$ and z represent the predicted and observed value at location x_0 and x_i respectively, n is the number of measured sample points used in the prediction, the weights (r) are related to distance by d_{ij}.

COMPOUND TOPOGRAPHIC INDEX (*CTI*)

CTI is a steady state wetness index and it is a function of both the slope and upstream contributing areas per unit width orthogonal to the flow direction. *CTI* has been found to be indicative of the position of a particular landform in the terrain. It is computed from the DEM using Equation (2), where As is the upstream area (number of upstream elements multiplied by the area of each grid cell) and β is the slope at a given cell [GESSLER *et al.* 1995; MOORE *et al.* 1993].

$$CTI = \ln(As/\tan\beta) \qquad (2)$$

USING TOPOGRAPHIC POSITION INDEX (*TPI*) FOR LANDFORM CLASSIFICATION

The *TPI* is simply the difference between a cell elevation value of each cell in a digital elevation model (DEM) and the average elevation of the neighbourhood around that cell. Negative values mean the cell is lower than its surroundings while Positive values mean it is higher [WEISS 2001]. *TPI* (Eq. (3)) compares the elevation of each cell in a DEM to the mean elevation of a specified neighbourhood around that cell. Mean elevation is subtracted from the elevation value at the centre (Tab. 2) [WEISS 2001]:

$$TPI_i = Z_0 - \frac{\sum_{n-1} Z_n}{n} \qquad (3)$$

Where: Z_0 = elevation of the model point under evaluation, Z_n = elevation of grid, n = the total number of surrounding points employed in the evaluation.

Table 2. Landform classification based on *TPI*

Class	Description
Canyons, deeply incised streams	small neighbourhood: $T_o \le -1$ large neighbourhood: $T_o \le -1$
Midslope drainages, shallow valleys	small neighbourhood: $T_o \le -1$ large neighbourhood: $-1 < T_o < 1$
Upland drainages, headwaters	small neighbourhood: $T_o \le -1$ large neighbourhood: $T_o \ge 1$
U-shaped valleys	small neighbourhood: $-1 < T_o < 1$ large neighbourhood: $T_o \le -1$
Small plains	small neighbourhood: $-1 < T_o < 1$ large neighbourhood: $-1 < T_o < 1$ slope ≤ 5°
Open slopes	small neighbourhood: $-1 < T_o < 1$ large neighbourhood: $-1 < T_o < 1$ slope > 5°
Upper slopes, mesas	small neighbourhood: $-1 < T_o < 1$ large neighbourhood: $T_o \ge 1$
Local ridges/hills in valleys	small neighbourhood: $T_o \ge 1$ large neighbourhood: $T_o \le -1$
Midslope ridges, small hills in plains	small neighbourhood: $T_o \ge 1$ large neighbourhood: $-1 < T_o < 1$
Mountain tops, high ridges	small neighbourhood: $T_o \ge 1$ large neighbourhood: $T_o \ge 1$

Source: own elaboration based on WEISS [2001].

RESULTS AND DISCUSSION

The spatial map of groundwater depth was generated using inverse distance weighting (IDW) from the well logs and shown in Figure 3. The water depth values had a wide range from 0 to 69.9 m. As shown in Figure 4, the values of *CTI* are from –13.4 to 5.1. By comparing Figures 3 and 4, it was determined that

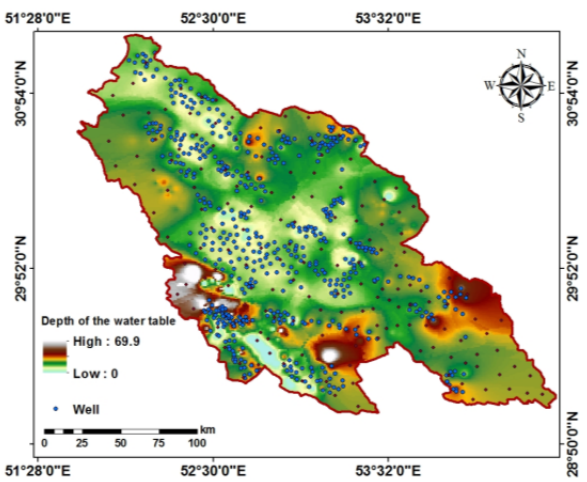

Fig. 3. Groundwater depth in the study area; source: own elaboration

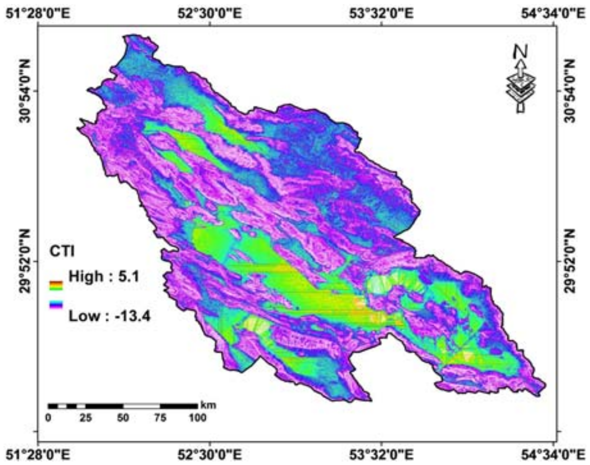

Fig. 4. Compound topographic index (*CTI*) map of the study area; source: own study

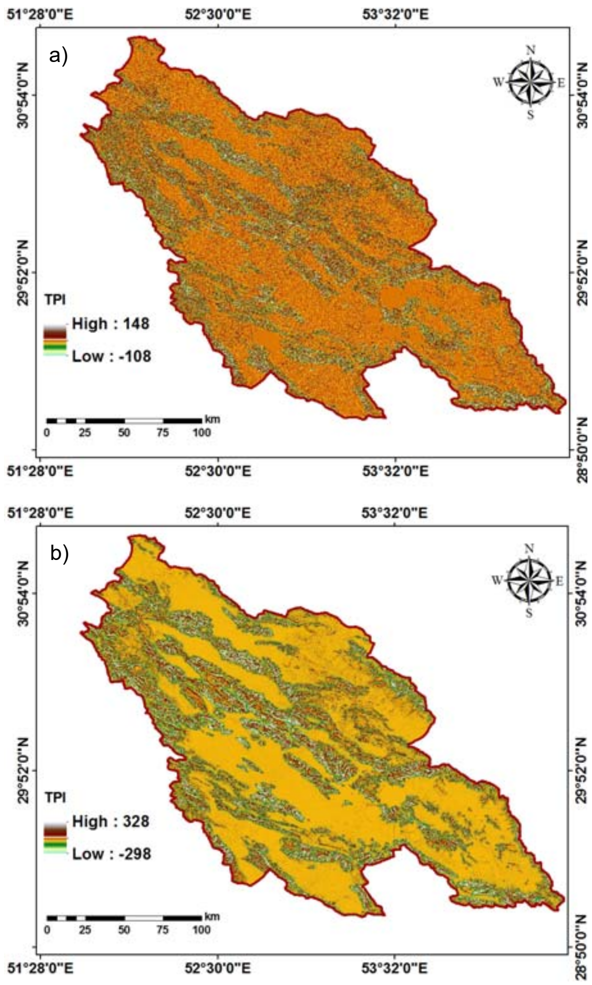

Fig. 5. Topographic position index (*TPI*) maps generated using (a) small (5 cells) and (b) large (45 cells) neighbourhoods; source: own study

areas with high depth of the water value have low *CTI* values, and vice versa.

The *TPI* maps generated using small and large neighbourhoods are shown in Figures 5. *TPI* is between –108 to 148 and –298 to 328 for 5 and 45 cell respectively (Fig. 5). The landform maps generated

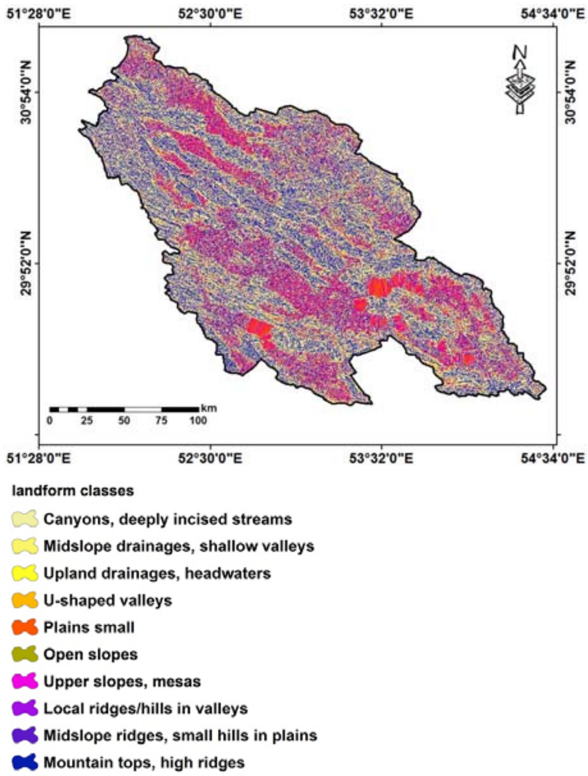

Fig. 6. Landform classification generated using topographic position index; source: own study

Table 3. Areas of the landform classes

Landform class	Area, %
Streams	8.32
Midslope drainages	4.31
Upland drainages	7.28
Valleys	18.42
Plains	1.73
Open slopes	30.87
Upper slopes	8.32
Local ridges	7.85
Midslope ridges	6.63
High ridges	6.27

Source: own study.

based on the *TPI* values are shown in Figure 6. The areas of the landform classes are shown in Table 3, where it is found that the largest landform is open slope, while the smallest are plains.

By comparing Figures 3 and 4 with Figure 7, *CTI* values and depth of the water are high in upland drainages and plain classes, while low in local ridges and mountain tops (Fig. 7). This is consistent in the findings of HALDAR *et al*. [2011], who found that the highest depth of the water and *CTI* were in the upland drainages and plain classes. High depth of the water was found to be mostly confined to the low regions in the plain landform as groundwater recharge occurs in the zones where standing water remains for sufficient long period of time and has favourable condition for recharge. Hence, based on these findings, we can predict the condition of depth of the water in different regions with landform classes (from satellite images

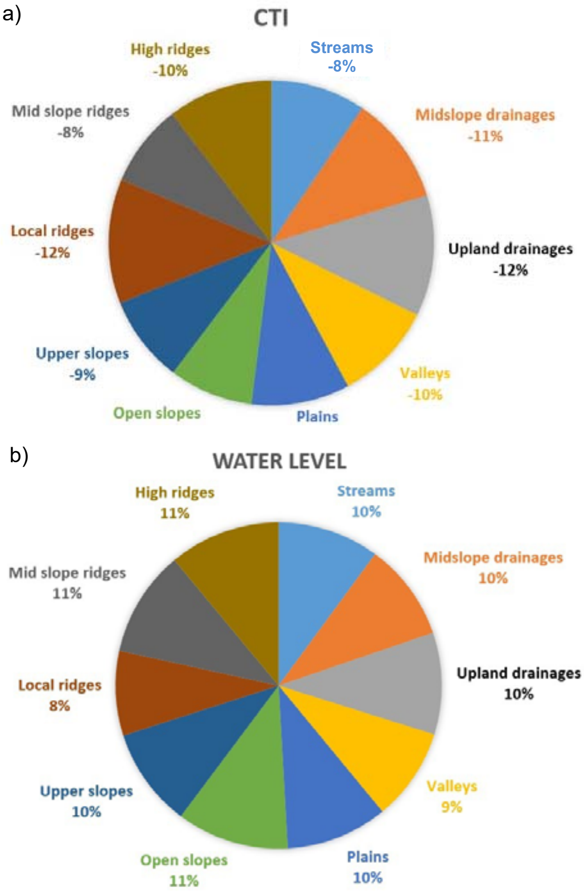

Fig. 7. Relationship between landform class with: a) compound topographic index (*CTI*) and b) depth of the water in the study area; source: own study

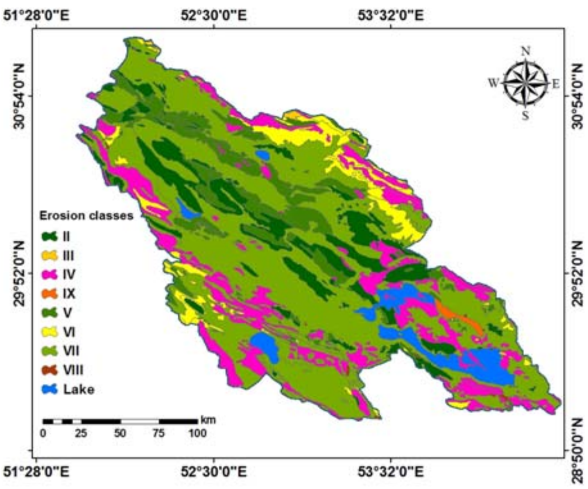

Fig. 8. Erosion sensitivity classes of extracting geology map; source: own elaboration acc. to Organization of Agriculture Jahad Fars

and DEM data) without direct measurement of depth of the water.

Finally, in order to determine the relationship between *CTI* value, landform, depth of the water and geology map erosion sensitivity classes was used (Fig. 8). The results showed that areas with high depth of the water (east and northwest and parts of south-east) had a high degree of erosion (class VI). Also, according to Figure 4 and 8, high *CTI* values were found in the class with high erosion class (VII). Also, the correlation between erosion and landform classes showed that the high erosion sensitive classes belonged to class 6 landforms.

The hydrological characteristics of a watershed are mainly the reflections from the existing salient features of its landforms or geomorphology. Geomorphology is a combination of physical geography and geology. It is the science of landform development and its development. So that it is closely related to earth's surface geology, hydrology and meteorology [THORNBURY 1954]. Analysis of landforms serves as the foundation of environs and earth sciences. Penck (1858–1945) was the first geographer who used the term 'geomorphology' to refer to the origin and development of the earth's surface landforms. So studies of landforms (geomorphology science) as very important branches of earth science can be used for prediction of other characteristic of watershed

CONCLUSIONS

Landscape topography is the most important driving force for groundwater flow and all scales of topography contribute to groundwater movement [MARKLUND, WÖRMAN 2007]. Groundwater quality is influenced by the climate, physiography, drainage and geology of the area. In fact there is a very strong linear correlation between topography and water table configuration. In the area, studies showed that depth of the water is the most strongly driven by topographic [CONDON, MAXWELL 2015; GLEESON *et al.* 2011]. Based on the findings of this study, depth of the water in regions with different landforms can be predicted from digital elevation models (DEMs) at low cost and high speed without sampling from wells. So, through studies of landforms and investigation of its relationships with other characteristics of the watershed such as climatology, hydrology, geology and so on, we can predict them using landform information.

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Użycie cyfrowego modelu wysokości (DEM) i systemu informacji geograficznej (GIS) do oceny zasobów wód gruntowych w odniesieniu do form ukształtowania terenu w zlewni Maharlou-Bakhtegan, prowincja Fars w Iranie

STRESZCZENIE

Badanie zasobów wodnych w stosunku do topografii jest istotne, ponieważ głębokość lustra wody jest różna w warunkach różnego ukształtowania terenu. Dlatego celem przedstawionych badań było ustalenie zależności między różnymi klasami form terenu o złożonym indeksie topograficznym (*CTI*) a głębokością wody w zlewni Maharlou-Bakhtegan (prowincja Fars, Iran). Do oceny głębokości wody w badanym obszarze pozyskano dane o *CTI* i geomorfologii z Shuttle Radar Topography Mission (SRTM) cyfrowego modelu wysokości (DEM). W wyniku analizy klas form ukształtowania terenu otrzymanych z użyciem topograficznego indeksu pozycji (*TPI*) stwierdzono, że największą część zajmowały otwarte stoki, a najmniejszą – równiny. Stwierdzono, że wartości *CTI* i głębokości wody były duże w klasie równin i niewielkie na lokalnych wzniesieniach. Duże głębokości wody były ograniczone głównie do regionów zagłębień w formach równinnych, ponieważ zasilanie wód podziemnych występuje w strefach, gdzie wody stojące utrzymują się wystarczająco długo i mają sprzyjające warunki do zasilania wód gruntowych.

Słowa kluczowe: *formy ukształtowania terenu, Maharlou-Bakhtegan, topograficzny indeks pozycji (TPI), wody podziemne, złożony indeks topograficzny (CTI)*