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

Marzieh MOKARRAM1) ABCDEF, Mehran SHAYGAN2) ABCDEF, Dinesh SATHYAMOORTHY3) ABCDEF

1) Shiraz University, Department of Range and Watershed Management, College of Agriculture and Natural Resources of Darab, postal code: 71946-84471, Iran; e-mail: m.mokarram@shirazu.ac.ir
2) Khaje Nasir Toosi University of Technology, Faculty of Geodesy and Geomatics Engineering, Tehran, Iran; e-mail: mehranshaygan@gmail.com
3) Science and Technology Research Institute for Defence (STRIDE), Malaysia; e-mail: dinesh.sathyamoorthy@stride.gov.my

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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 K RISHNA 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...
Singer 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 Khenchelca 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 [Rasamei 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 km² 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 1,444 m to 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 m³. Groundwater resources supply 79% of the total water needs in the catchment [Rasamei 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. 1. Location and Shuttle Radar Topography Mission digital elevation model of the study area; source: own elaboration

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

$$\hat{z}(x_0) = \frac{\sum_{i=1}^{n} x_i d_i^{-p}}{\sum_{i=1}^{n} d_i^{-p}}$$ (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 $d_i$.

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 $\beta$ is the slope at a given cell [GESSLER et al. 1995; MOORE et al. 1993].

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

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 cell. Mean elevation is subtracted from the elevation value at the centre (Tab. 2) [WEISS 2001]:

$$TPI_i = Z_0 - \frac{\sum_{n=1}^{n} Z_n}{n}$$ (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: $T_c \leq -1$                                          |
|                                | large neighbourhood: $T_c < 1$                                              |
| Midslope drainages, shallow valleys| small neighbourhood: $T_c \leq -1$                                          |
|                                | large neighbourhood: $T_c > 1$                                              |
| Upland drainages, headwaters   | small neighbourhood: $-1 < T_h < 1$                                         |
|                                | large neighbourhood: $T_h \geq 1$                                           |
| U-shaped valleys               | small neighbourhood: $-1 < T_u < 1$                                         |
|                                | large neighbourhood: $1 \leq T_u$                                           |
| Small plains                   | small neighbourhood: $1 < T_s < 1$                                         |
|                                | large neighbourhood: $T_s \leq 1$                                          |
| Open slopes                    | small neighbourhood: $-1 < T_o < 1$                                         |
|                                | large neighbourhood: $1 < T_o < 1$                                         |
| Upper slopes, mesas            | small neighbourhood: $-1 < T_u < 1$                                         |
|                                | large neighbourhood: $T_u > 5^\circ$                                       |
| Local ridges/hills in valleys  | small neighbourhood: $T_r \geq 1$                                          |
|                                | large neighbourhood: $T_r \leq 1$                                          |
| Midslope ridges, small hills in plains | small neighbourhood: $T_r \geq 1$                                          |
|                                | large neighbourhood: $T_r \leq 1$                                          |
| Mountain tops, high ridges     | small neighbourhood: $T_m \geq 1$                                          |
|                                | large neighbourhood: $T_m \leq 1$                                          |

Source: own elaboration based on WEISS [2001].

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
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 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...
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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

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 southeast) 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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Marzieh MOKARRAM, Mehran SHAYGAN, Dinesh SATHYAMOORTHY

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 wód 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)