The Relationship between Precipitation and Topography in Northern Jordan using Principal Component-Based GIS Analysis

Mohammad Bani Doomi *

ABSTRACT

The factors that influence precipitation in northern Jordan were extracted from geographic variables using Principal Component-based GIS analysis. The analysis was carried out on a cell basis, where interpolation of the amount of precipitation was performed using a thin spline method and the elevation surface using an Inversed Distance Weighted (IDW) method. The examined variables were elevation above sea level, slope, aspect, and geographical location (east coordinates and north coordinates) all over the study area. The results showed a positive correlation between the amount of precipitation and slope and the amount of precipitation and elevation, while a negative correlation was existed with geographical location. The latter variable seems to have no effect on the amount of precipitation in the region or either its distribution.

Keywords: Precipitation, Topography, GIS, Jordan.

Introduction

Topographic variables influence the precipitation type and distribution (Basist, Bell, and Meentemeyer, 1994), where the latter usually occurs when air in the lower layers of atmosphere is raised by the solar radiation, or when two different air masses meet around a low pressure region, or when humid air travels over a mountain, which is called orographic precipitation (Naoum and Tsanis, 2004). The factors that may contribute to the variation in the distribution of the annual precipitation in a given region may include elevation above sea level, slope, aspect, altitude, latitude, distance to the sea and radii of principal curvature (Osborn, 1984) (Puvaneswaran and Smithson, 1991) (Weissee and Bois, 2001) (Marquinez, Lastra, and Gracia, 2003) (Naoum and Tsanis, 2004). The correlation between these factors was approached using one or more of the methods: principal component analysis (Fernandez, 1995), factorial analysis (Maheras, 1985), multiple regression analysis (Um, Yun, Cho, and Heo, 2010), or Geographic Information System (Goodale and Ollinger, 1998) (Marquinez, Lastra, and Gracia, 2003) (Ninyerola, Pons, and Roure, 2000).

Many of the previous studies on the relationship between precipitation and topography did not examine the local complex interactions occurring between topography and the local climate, but regional ones, which is substantially covered larger areas (Maheras, 1985) (Nullet and McGranaghan, 1988) (Kadioglu, 2000) (Um, Yun, Jeong, and Heo, 2011). These areas tend to weaken the spatial resolution of the data as the latter is usually interpolated from sampled sites of varying distances and topographies.

Aim of Study

This study focuses on the northern part of Jordan to examine the correlations between precipitation and topography, the cell-based analysis using GIS is assumed to give better results compared to point methods employed by various researchers worldwide, where the former uses the value of each raster cell in the model although its location might be far from the meteorological station.

Area of Study

The study area is located in the northwestern part of Jordan, where the borders of Syria, Jordan and Palestine
meet. The area is agriculturally productive despite its
small size, which is about 2641.26 km² (73.2 km north-
south and 49.8 km east-west) (fig1). The annual amount
of precipitation is spatially variable and reduces in the
east direction as an effect of weakened eastern
Mediterranean winds, where it ranges from 95 mm-714
mm. In addition to meteorological variability, the
topography is extremely variable; the elevation ranges
from -295 m to 1153 m above sea level. Unfortunately
most of the area is dependent upon rainfall in agriculture
except for Jordan Valley where crops are irrigated
through shallow canals that are branched from the
diminished Jordan River. These extremes in meteorology
and topography have created unique faunal and floral
biodiversity, and enhanced intensive agriculture.

Fig. 1: The Study Area
Data collection and methods

The elevation of the sample locations in the study area were previously collected by the Department of Antiquities in Jordan using the Palestine Grid as a coordinate system. The data was interpolated using ArcGIS 9.2 software using the ‘Inversed Distance Weighted’ (IDW) method due to the fact that sampled locations are distributed throughout the study area and not clustered. IDW interpolation assumes that elevation points that are close to one another are more likely to be equal roughly than those far ones. To predict a value for unknown elevations, IDW uses the measured elevation values surrounding the prediction location, where each measured point has a local influence on the predicted ones that diminishes with distance. The total number of the collected elevation points is 1723 points and are distributed throughout the study area as shown in (fig 2) below.

The interpolated elevation layer explicitly shows the variation in topography in the study area (fig 3). The nature of this topography has created a network of storm water flow that runs across the steep slopes of the area and discharges into the Jordan Valley (Fig. 3).

Fig2: Area of study and the sampled elevation points.
The factors that are included in the analysis and expected to have a correlation with the amount of precipitation are the slope, the aspect, geographic location (East and North coordinates\(^1\)) and the elevation above sea level. Each of these factors was represented in ArcGIS 9.2 as a separate layer, where the first two were extracted from the interpolated elevation layer using surface analysis (figs 4 and 5).

The annual amount of precipitation was obtained from the distributed 9 meteorological stations throughout the study area fig. 6 and fig.7, and see also table 1). The available data at these stations are available for the period from 1985-2011, where the average annual amount was interpolated using the thin spline method because the number of the interpolated points is not large as in IDW, the variation in the amount of precipitation is gradual, and appropriate due to the gradual changes in the surface within a short horizontal distance.

The principal component analysis (PCA) was used to extract the covariance and correlation among the six variables (precipitation, aspect, slope east coordinate, north coordinate and elevation). PCA is used to transform the data attributes in a raster dataset from the input multivariate attribute space to a new multivariate attribute space whose axes are rotated with respect to the original space. The axes in the new space are uncorrelated. The main reason here is to emphasize the variance within raster datasets and extract the correlation.

Results and Discussion

The correlation matrix given in table 2 below shows that the highest correlation exists between the annual amount of precipitation and geographic location (in terms of north and east coordinates), where the correlation between precipitation and Palestine north and east coordinates (PGN and PGE) is about -0.46 and -0.37 respectively. This means that the annual amount of precipitation is decreased toward the farthest north and the farthest east. The decrease in the northern direction is attributed to the absence of high mountains in this area \((r\text{ between PGN and elevation }\approx0.21\)) while in the east direction is probably attributed to the weakened fronts as they usually enter the region from the west. In addition, the elevation above sea level increases in the eastern direction, which blocks winter fronts from reaching the farthest eastern areas in full intensity; the correlation between PGE and elevation is about 0.59.

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\(^1\) The geographical location is an important factor due to the fact that it reflects the distance between each location in the study area and the Mediterranean sea which is an important variable that affects the amount of precipitation.
Fig 4: Aspects within the study Area

Fig 5: Slopes within the study area
Table (1): The average amount of precipitation (1985-2011) of the meteorological stations in the study area.

<table>
<thead>
<tr>
<th>Station Name</th>
<th>East*</th>
<th>North*</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irbid</td>
<td>229800</td>
<td>1218400</td>
<td>481.07</td>
</tr>
<tr>
<td>Ras-Muneef</td>
<td>240500</td>
<td>1177100</td>
<td>617.20</td>
</tr>
<tr>
<td>Albaqura</td>
<td>207228</td>
<td>1227676</td>
<td>416.63</td>
</tr>
<tr>
<td>Ramtha</td>
<td>245000</td>
<td>1218600</td>
<td>232.23</td>
</tr>
<tr>
<td>Taybah</td>
<td>218416</td>
<td>1219659</td>
<td>440.17</td>
</tr>
<tr>
<td>Dierabusaeed</td>
<td>214600</td>
<td>1211400</td>
<td>481.54</td>
</tr>
<tr>
<td>KufirAwan</td>
<td>214800</td>
<td>1203600</td>
<td>488.27</td>
</tr>
<tr>
<td>Rehaba</td>
<td>224000</td>
<td>1204500</td>
<td>562.91</td>
</tr>
<tr>
<td>Jerash</td>
<td>234100</td>
<td>1187600</td>
<td>397.71</td>
</tr>
</tbody>
</table>

(*) The coordinates are based on Palestine Grid.

Fig. 6: the spatial distribution of meteorological stations within the study area
The aspect seems to have little if any relationship with annual amount of precipitation ($r \approx -0.01$). In GIS, aspect identifies the down slope direction of the maximum rate of change in value from each cell to its neighbors, in other words the slope direction. Practically, aspect is correlated with the prevailing wind over a geographical area, the previous studies in other parts of the world emphasized on the effect of the prevailing wind on the amount of precipitation (Hutchinson, 1973) (Houghton, 1979). The correlation between aspect and the annual...
amount of precipitation is masked by the weak correlation between slope and aspect ($r \approx 0.07$). The Histogram of the aspect of the region shows that most of the aspects are not eastern with a very high standard deviation (SD. $\approx 17$) (fig 8).

Fig 8: Histogram of the Aspect map of northern Jordan.

Fig 9: The areas of similar topographic variables within the study area (in northern Jordan).
There is a proportional correlation between precipitation and the slope % in the study area ($r \approx 0.21$). The various slopes are located throughout the study area and not clustered in one region (fig 5), but the aerial precipitation might have better correlation if examined. The results also demonstrate a proportional correlation between the annual amount of precipitation and the elevation above sea level ($r \approx 0.15$). The relationships among the four variables coexisted in the region in a specific pattern that is summarized by (fig 9) below, which demonstrates the areas of similar topographic variables (good correlation) in the same color.

**Conclusions**

Four topographic variables can cause effect on the amount of precipitation in northern Jordan, east coordinate, north coordinate, elevation above sea level and slope, where the first two variables have a negative correlation and the latter variables (elevation and slope) have a positive correlation on precipitation. The use of GIS in this study ensured better spatial resolution more accuracy but could have been improved, with the presence of data from more meteorological stations in the region. Future studies in the region should include other variables as well, such as, the establishment of new dams, hydrological projects, land use and land cover (which we assume it will affect the amount of precipitation with the study area).

**REFERENCES**


العلاقة بين الهطول المطري والتضاريس في شمال الأردن

باستخدام مكونات نظم المعلومات الجغرافية

محمد بني دومي*

ملخص

تعد العوامل الجغرافية من المؤثرات الرئيسية التي تؤثر في تساقط الأمطار في شمال المملكة الأردنية الهاشمية، وقد تم استخدام مكونات نظم المعلومات الجغرافية لأغراض تحليل أثر هذه المتغيرات، حيث اعتمد نظام أساس الخليفة لغيات استخراج كميات الهطول باستخدام أسلوب الخليفة والأسلوب المرجح للارتفاعات. المتغيرات التي تم فحصها الارتفاع فوق مستوى سطح البحر، والتحصيل، والانحدار، والمنطقة البنائية في جميع أنحاء منطقة الدراسة. وأظهرت النتائج وجود علاقة إيجابية بين كمية الأمطار والانحدار وكمية هطول الأمطار والارتفاع، في حين كان هناك علاقة سلبية مع باقي المتغيرات. واستثناء الاتجاه، ويبدو أن الأخير لا يكون له تأثير على كمية هطول الأمطار وتوزيعها في منطقة الدراسة.

الكلمات الدالة: المناخ، الأمطار، الطبوغرافيا، نظم معلومات جغرافية.