Journal of Natural Sciences Research
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.7, No.6, 2017

The Use of Vector-Based GIS and Multi-Criteria Decision Making (MCDM) for Siting Water Harvesting Dams in Karak Governorate/ South Jordan

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Abstract
Jordan is the 4th poorest country in the world in terms of water resources. Although, Jordan receives an average annual rainfall of 8194 million cubic metre, it can only collect 360 million cubic meters in its existing dams. There is an urgent need to construct more dams in order to harvest the obtainable runoff which might help in overcoming the shortage in its water resources for domestic and agricultural uses. Site selection of dams must be carried out using sophisticated tools and techniques. One of these techniques is GIS, which could be integrated with multi-criteria decision making (MCDM) to select the optimum sites for dams. In this research vector-Based GIS and multi-criteria decision making were used to select the optimum sites of dams in Karak governorate/ South Jordan. Rainfall, soil, slope, urban areas and roads comprise the selection criteria used in this research based on the use of weighted linear combination (WLC). Wadis, Roads, Urban Centres, Faults and Wells comprise the constraint factors used to erase the unsuitable areas for constructing dams based on the Boolean technique. The outcome of this research showed that there are 9 potential sites that could be utilized for constructing dams to harvest the surface water in the study area.
Keywords: Jordan; Karak; Dams; Vector-Based; GIS; MCDM

1. Introduction

Jordan is a country with limited water resources. It is currently the 4th poorest country in the world in terms of available water resources for its people and the millions of refugees from neighboring countries. According to the Water Authority of Jordan (WAJ, 2013), the average amount of rainfall that fall on Jordan is 8194 million cubic metre (MCM) annually. The annual domestic water consumption in Jordan is 381 MCM of which 123 MCM come from surface water resources. The agriculture sector in Jordan consumes 475 MCM annually of which 225 MCM from surface water resources (WAJ, 2013). In Jordan, there are several dams with a total capacity of 360 MCM (WAJ, 2013). This emphasizes the need to construct more dams at various locations in Jordan. The optimum sites for future dams must rely on sophisticated techniques. GIS has been adopted by various researchers to select the best sites for water harvesting schemes (Ponds and Dams). Weighted Linear Combination (WLC) and the Boolean techniques (Malczewski, 2004) are the most commonly used approaches in siting projects within GIS Environment.

WLC is an index overlay technique (Eastman, 1997). It involves the followings steps (Malczewski, 2004; Yalcin, 2008):

1. Maps standardization (ratings),
2. Maps weighting based on their relative importance,
3. Multiplying maps weights by their ratings,
4. Overall suitability score is calculated by combining all maps, and
5. Classifying the final map into several classes based on the project requirement.

WLC has been adopted in several researches (Baban and Wan-Yusof, 2003; Ayalew *et al*. 2005; Yalcin, 2008; Shatnawi, 2006; Al-Adamat, *et al*., 2010 and Al-Adamat *et al*., 2012). The researchers used the Raster GIS to conduct their project, where all maps were converted to Raster after assigning the ratings by manipulating the attribute table of each layer. All layers were then summed after multiplying each one of them by its weight. The Boolean techniques is based on classifying each map into two classes; not suitable and suitable (Madrucci, *et al*., 2008). In Raster GIS, these two classes are assigned 0 for not suitable and 1 for suitable. The final layer in this technique is the outcome of multiplying all layers. This techniques has been used in many researches (Al-Adamat, 2008; Chang, and Breeden, 2008; Longdill *et al*., 2008; Ghayoumian *et al*., 2007). According to Jankowski, (1995), it is possible to carry out a multiple criteria evaluation using vector-based GIS. It is argued by Jankowski, (1995), that the multiple criteria evaluation using vector GIS produce relatively small number of suitable alternatives in comparison with raster GIS. It is concluded by Jankowski, (1995), that there is a possibility to integrate vector-based GIS and MCDM techniques. Based on Heywood *et al.* (2002), the use of vector-based GIS for decision making could be achieved by employing the selection criteria on the attributes of geographic features.

Weighted Linear Combination (WLC) can be easily implemented in both vector and raster formats. In Raster GIS, the weighted overlay operators allow the performance of the addition and multiplication operations on a pixel-by-pixel basis (Demesouka, *et al*., 2014). In a vector-based GIS context, attributes of geographic features may serve as decision criteria (Longley *et al.* 2001). Vector-based GIS has been used for projects site selection in several researches (e.g. Basaiaoclu *et al*., 1997; Lin and Kao, 1998 and Ahesan, and Masron, 2015). Based on that, this research will be an attempt to document the necessary steps to implement both techniques (WLC and Boolean) within a vector GIS environment. For this purpose GIS will be used to select optimum sites for water harvesting dams in Karak governorate/ South Jordan.

2. Study Area

The study area (3340 km2) is located in the Southern part of Jordan to the East of the Dead Sea (Figure 1). The study area is inhabited by more than 316,600 people (Figure 2) (DOS, 2015). The clay percentages of soil in the study area (Figure 3) vary between 12 in the west to 30% in the East. The study area is characterised by hot dry summers and wet cold winters. The average annual rainfall varies between 50 mm in the south west to 400 mm in the central part of the study area (Figure 4). The study area topography is dominated with regions of high elevation in the South and others below sea level in the West. Elevation over the study area varies between around 400 m below Sea level near the Dead Sea in the West to 1500 m above Sea level in the South (Figure 5). The direction of surface water flow in the study area is towards the North West and West following the South East–North West topographic slope (Figure 6).

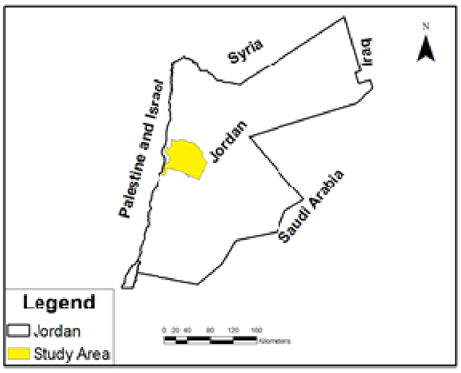


Figure 1. Study area location within Jordan

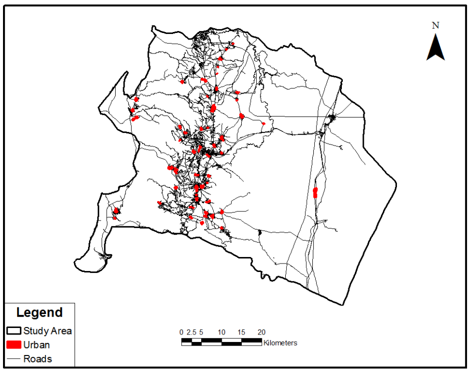


Figure 2. Populated areas within the study area

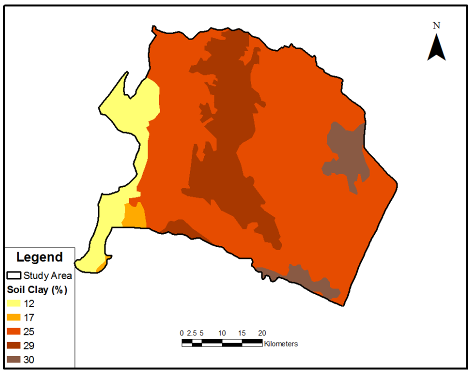


Figure 3. Soil clay percentages within the study area

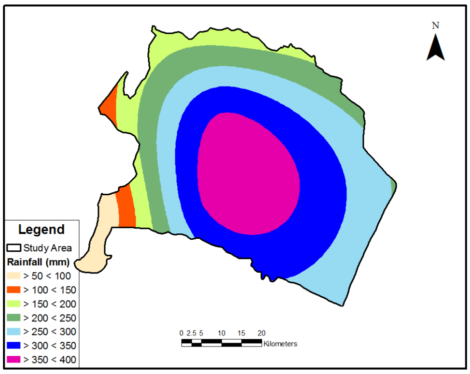


Figure 4. Rainfall isohyets within the study area

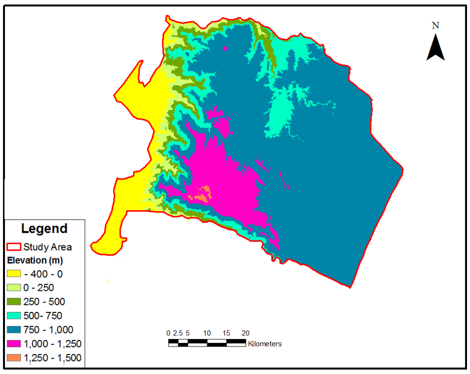


Figure 5: Elevation within the study area

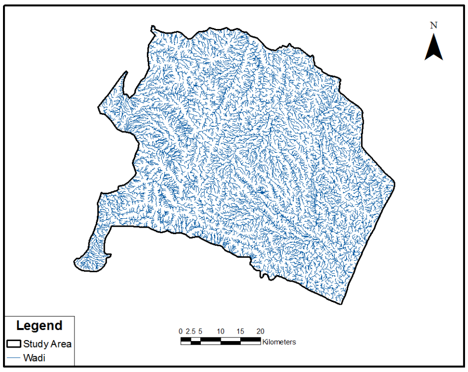


Figure 6: Wadis within the study area

3. Methodology

3.1. Site Selection Criteria

The selection criteria used in this research is based on previous researches conducted by Critchley, et al., (1991); Yang (2003); Shatnawi, (2006); Al-Adamat, (2008); Al-Adamat, et al., (2010) and Al-Adamat et al., (2012). Table (1) lists the weights and rating for five WLC criteria. The selection criteria include; Rainfall, Slope, Soil (Clay %), Urban Centres and Roads. In combination with these criteria, five constraint factors were used to eliminate unsuitable areas. Table (2) lists the constraint factors which include; Wadis, Roads, Urban Centres, Faults and Wells (Shatnawi, (2006) and Al-Adamat, (2008)).

Table 1. Weights and ratings for the selection criteria

Parameters	Weight	Ratings			
		4	3	2	1
Rainfall (mm)	5	≥ 500	≥ 300 < 500	≥ 100 < 300	< 100
Slope (%)	4	< 3	≥ 3 < 5	≥ 5 < 10	> 10
Soil (Clay contents) (%)	3	≥ 35	≥ 18 < 35	≥ 10 < 18	< 10
Distance to urban Centres (m)	2	< 500	≥ 500 < 1000	≥ 1000 < 2000	≥ 2000
Distance to Roads (m)	1	< 500	≥ 500 < 1000	≥ 1000 < 2000	≥ 2000

Table 2. Constraint factors

Factors	Allowed	Not Allowed
Distance to Wadis (m)	≤ 50	> 50
Distance to Roads (m)	> 250	≤ 250
Distance to Urban Centres (m)	> 250	≤ 250
Distance to Faults (m)	> 1000	≤ 1000
Distance to Wells (m)	> 500	≤ 500

Based on Table (1), the potential WLC outcome will generate values between 15 and 60. This outcome will have the following ranges (Table 3) if classified into 3 suitability classes: low, moderate and high.

Table 3. WLC classification

Class	Low	Moderate	High
Range	15 - 30	30 - 45	45 - 60

3.2. Data Collection

The secondary data sets to conduct this research have been obtained from different government agencies in Jordan and from international organization. These data include:

1. Landsat 8 imagery of September, 2016 (30 m resolution) which has been used to extract the urban centres within the study area using unsupervised classification,
2. ASTER (ASTER Advanced Spaceborne Thermal Emission and Reflection) digital elevation model (30 m resolution) which has been used to extract the slope percentages in the study area. It was also used to extract the drainage network (Wadis) using flow direction and flow accumulation tools in ArcGIS®.
3. Wells' locations were obtained from the Water Authority of Jordan.
4. Soil data were provided by Jordan Ministry of Agriculture,
5. Rainfall isohyets were obtained from previous research (Al-Adamat et. al, 2007).

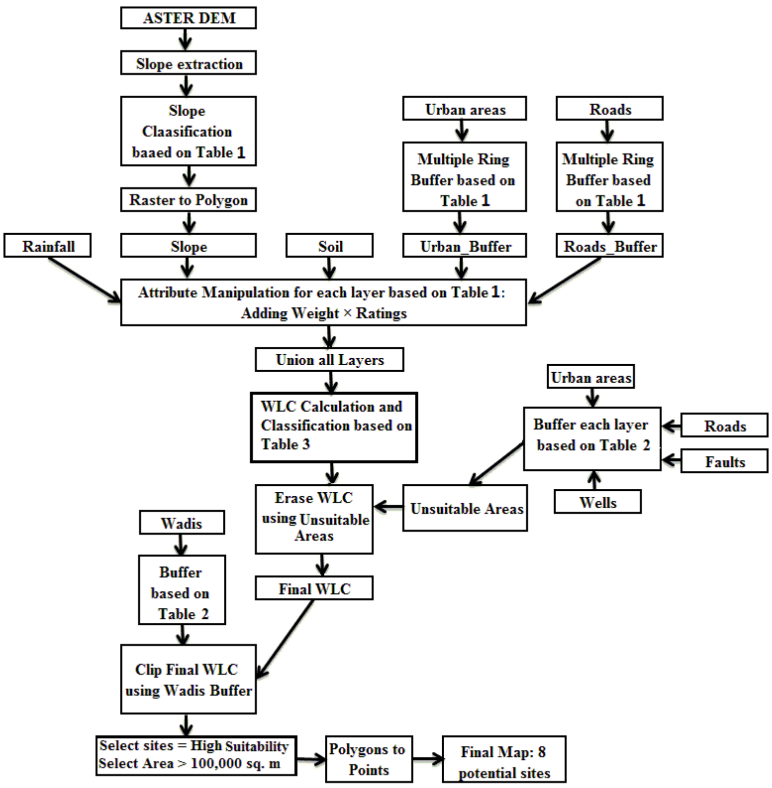
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.7, No.6, 2017

6. Faults data were acquired from the Natural Resources Authority of Jordan,
7. Roads were downloaded using QGIS (A Free and Open Source Geographic Information System).

4. Data Analysis and Results

In this research, the vector GIS analysis tools were used to implement the WLC and the Boolean techniques. The following flowchart (Figure 7), illustrate the adopted methodology to select the optimum sites for dams in the study area. The major steps adopted in this research to analyse the data include the followings:

1. Slope extraction from ASTER DEM and reclassification based on Table (1)
2. Raster to Polygon conversion for the slope layer,
3. Multiple ring buffer to account for the buffer distances listed in Table (1),
4. Attribute manipulation by adding the weight × ratings for each layer listed in Table (1) (Figures: 8 – 12),
5. Union all layers that comprise the WLC criteria,
6. Calculate the WLC by adding the weight × ratings for all layers (Table 4),
7. Classify the WLC layer according to Table (3) (Figure 13),
8. Buffer each layer listed in Table (2) based on the appropriate buffer distance,
9. Union all buffered layers (Table 2) to generate a single layer for the unsuitable areas (Figure 14),
10. Erase the WLC layer using the unsuitable areas layer (Figure 15),
11. Select the sites that have high suitability (Figure 16) and
12. Select the sites that have areas of more than 10 ha (100,000 m2) and convert the final suitable sites into points layer that have the centre coordinate of each suitable site (Figure 17).



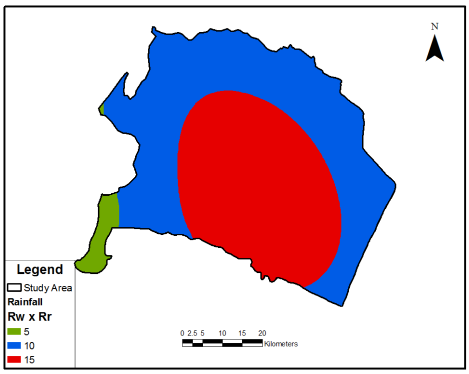


Figure 7. Data Analysis methodology

Figure 8. Rainfall parameter

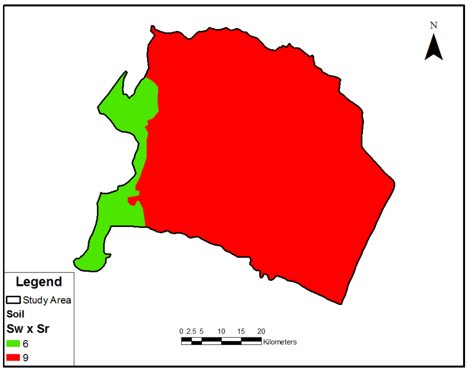


Figure 9. Soil parameter

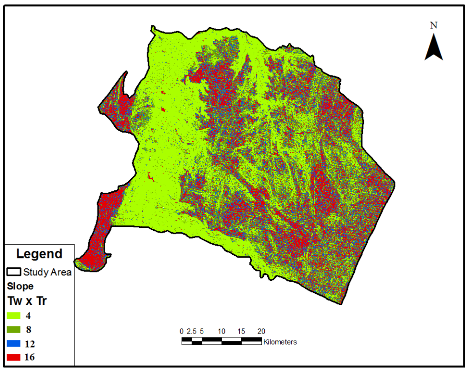


Figure 10: Slope parameter

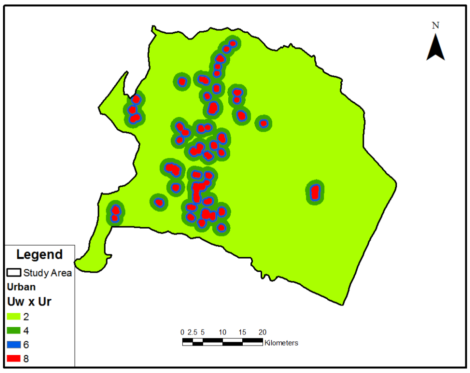


Figure 11: Urban parameter

Figure 12. Road parameter

Table 4. Sample of WLC calculation

ID	Rw x Rr	Tw x Tr	Sw x Sr	Lw x Lr	Row x Ror	Total	Class
1	5	4	6	2	1	18	Low
2	5	4	6	2	4	21	Low
3	15	4	9	2	4	34	Moderate
4	15	16	9	4	3	47	High

Table (5) summarises the WLC parameters calculation (weight × ratings) where rainfall varies between 5 and 15. Most of the study area has scores of 10 and 15 (96.9%), the remaining 3.1% has a score of 5. Slope scores vary between 4 and 16, where the highest percentage of study area (39.2%) (1309.2 km2) has a score of 4. The slope with a score of 16 has an area of 685.4 km2 (20.5% of total area). Soil has two scores; 6 with an area of 329.4 km2 (9.9% of total area) and 9 with an area of 3010.6 km2 (90.1% of total area). Urban areas contributed to the final WLC with values of 2 (81.3%), 4 (10.4%), 6 (4.7%) and 8 (3.5%). Roads have scores of 1 (24.1%), 2 (18.2%), 3 (17.4) and 4 (40.3%).

Table 5. WLC parameters calculation

Rainfall			Slope			Soil		
Rr×Rw	Area (km^2)	%	Tw×Tr	Area (km^2)	%	Sw×Sr	Area (km^2)	%
20	0	0	16	685.4	20.5	12	0	0
15	1478.9	44.3	12	508.3	15.2	9	3010.6	90.1
10	1758.3	52.6	8	837.1	25.1	6	329.4	9.9
5	102.8	3.1	4	1309.2	39.2	3	0	0

Urban			Roads		
Uw×Ur	Area (km^2)	%	Row×Ror	Area (km^2)	%
8	117.7	3.5	4	1347.6	40.3
6	156.7	4.7	3	581.7	17.4
4	349	10.4	2	606.7	18.2
2	2716.6	81.3	1	804	24.1

Table (6) summarizes the WLC classes (High, Moderate and Low) before (Figure 13) and after erasing

(Figure 15) the unsuitable areas (Figure 14). It appears that the areas with high suitability has decreased from 184.2 km2 to 57.5 km2, while moderate and low suitability areas have decreased from 988.4 km2 and 2167.4 km2 to 512 km2 and 1062.9 km2 respectively. Overall, the unsuitable layer (Figure 14) has erased 1707.4 km2 of the study area (51.2%). In this research, the areas with high suitability (57.5 km2) (Figure 16) were subjected to further analysis. Each polygon with an area of 10 ha or more was selected as a suitable site to construct dams. The suitable polygons were converted to points layer that indicate the center of these polygons, where 9 potential sites generated in this step (Figure 17).

Table 5: WLC Classes

Class	Area (km^2) before erasing unsuitable areas	Area (km^2) after erasing unsuitable areas	Difference	%
High	184.2	57.5	126.7	68.78
Moderate	2167.4	1062.9	1104.5	51
Low	988.4	512	476.4	48.2
Total	3340	1632.4	1707.6	51.2

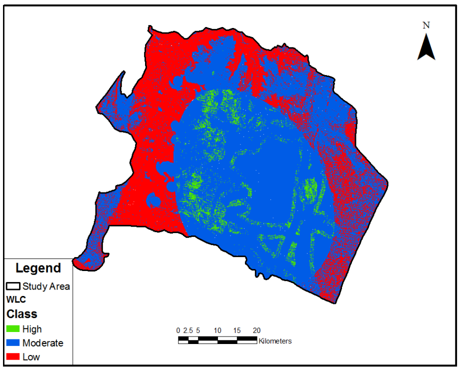


Figure 13. WLC outcome

Figure 14: The unsuitable areas

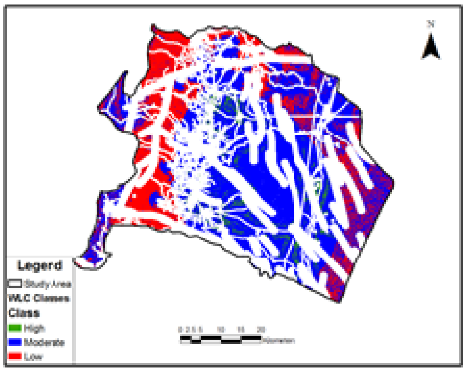


Figure 15. The combination of WLC and Boolean

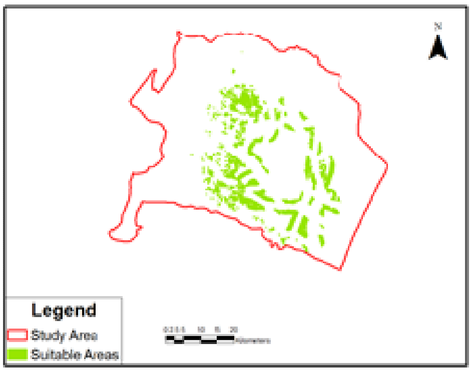


Figure 16. The suitable areas

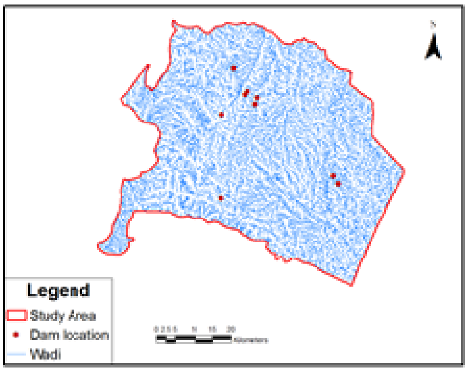


Figure 17: The suitable sites with areas of more than 10 ha

5. Conclusion and Recommendations

In this research a vector-Based GIS and MCDM were used in order to select the optimum sites for water harvesting dams in Karak governorate/ South Jordan. Both WLC and Boolean techniques were adopted using vector analysis tools such as Multiple Ring Buffer, Buffer, Union, Clip and Erase on several GIS maps to select the optimum sites for dams. Attribute manipulation was applied to calculate the WLC score based on the weight × ratings of 5 criteria; rainfall, slope, soil, distance to urban centres and distance to roads. The unsuitable areas were erased from final WLC layer using 5 constraint factors; wadis, roads, urban centres, faults and wells. The final map was classified into 3 suitability classes; low, moderate and high. Only sites with high suitability and area of more than 10 ha were chosen and converted into points layer.

Based on the outcomes of this research, it's concluded that vector-based GIS has the capability to handle digital data for MCDM to select optimum sites for water harvesting dams. Vector analysis tools could be utilized to match the raster arithmetic calculation capabilities. In vector-based GIS, union tool in combination with attribute manipulation to handle the summation of weights × ratings of all layers could be used instead weighted sum in raster. Also, the erase tool could compensate for the converting GIS layers into 0 and 1 cells in raster to eliminate unsuitable areas when selecting optimum sites for any project. Finally, the vector overlay method was found to be useful in producing a map that differentiates suitable and unsuitable areas.

Based on these conclusions, it is recommended to use vector-based GIS in combination with MCDM for selecting optimum sites of dams.

6. References

1. Ahesan, M. A., & Masron, T. B. (2015). GIS Application to Determine Suitable Sites for Automatic Rice Mills in Joypurhat District, Bangladesh. International Journal of Advanced Remote Sensing and GIS, Vol. (4), No. (1), pp. 883-894.
2. Al-Adamat, R., (2008), GIS as a Decision Support System for Siting Water Harvesting Ponds in Jordan*, Journal of Environmental Assessment Policy and Management*, Vol. (10), No. (02), pp. 189-206.
3. Al-Adamat, R., AlAyyash, S., Al-Amoush H., Al-Meshan O., Rawajfih Z., Shdeifat A., Al-Harahsheh A., and Al-Farajat M., (2012), the combination of indigenous knowledge and geo-informatics for water harvesting siting in the Jordanian Badia, *Journal of Geographic Information System*, Vol. (4), No. (4), pp. 366-376.
4. Al-Adamat, R., Diabat, A., and Shatnawi, G. (2010). Combining GIS with multicriteria decision making for siting water harvesting ponds in Northern Jordan. *Journal of Arid Environments*, Vol. (74), No. (11), pp. 1471-1477.
5. Al-Adamat, R., et al., (2007), predicted soil organic carbon stocks and changes in Jordan between 2000 and 2030 made using the GEFSOC Modelling System. In: Milne, E., Powlson D.S., and Cerri, C.E.P. (Eds.), Soil Carbon stocks at regional scales. *Journal of Agricultural Ecosystems and Environment*, Vol., (122), No. (1), pp. 35-45.
6. Ayalew, L., Yamagishi, H., (2005). The application of GIS-based logistic regression for landslide susceptibility mapping in the Kakuda-Yahiko Mountains, Central Japan. *Geomorphology*, Vol. (65), pp.15-31.
7. Baban, S., and Wan-Yusof, K., (2003), Modelling Optimum Sites for Locating Reservoirs in Tropical Environments, *Water Resources Management*, Vol. (17), No. (1), pp. 1-17.
8. Basaiaoclu, H., Celenk, E., Mariulo, M.A. and Usul, N. (1997), Selection of Waste Disposal Sites Using Gis1. Journal of the American Water (Resources Association, Vol. (33), No. (2) pp. 455-464.
9. Chang, Ni-Bin, Parvathinathan, and Breeden, Jeff. B., (2008), Combining GIS with fuzzy multicriteria for landfill siting in a fast-growing urban region, *Journal of Environmental Management*, Vol. (87), pp. 139-153.
10. Critchley, W., Siegert, K., and Chapman, C., (1991), Water harvesting, A manual Guide for the design and construction of water harvesting schemes for plant production, FAO, Rome, Found at: http://www.fao.org/docrep/u3160e/u3160e00.htm, last accessed March, 2017.
11. Demesouka, O. E., Vavatsikos, A. P., & Anagnostopoulos, K. P. (2014). GIS-based multicriteria municipal solid waste landfill suitability analysis: A review of the methodologies performed and criteria implemented. Waste Management & Research, Vol. (32), No. (4), pp. 270-296.
12. DOS (Jordan Department of Statistics), (2015), the Jordan national population censuses for 2015, internal report, Amman, Jordan.
13. Eastman, J.R., (1997), Idrisi for Windows, User´s Guide, Version 2.0, Clark Labs for Cartographic Technology and Geographic Analysis, Clark University.
14. Ghayoumian, J., Saravi, M.Mohseni., Feiznia, S. Nouri, B., and Malekian, A., (2007), Application of GIS techniques to determine areas most suitable for artificial groundwater recharge in a coastal aquifer in southern Iran, *Journal of Asian Earth Sciences*, Vol. (30), pp. 364 .374
15. Heywood, I., S. Cornelius, S. Carver (2002). An introduction to Geographical Information Systems. Pearson Education, Harlow (UK).

16. Jankowski, P., (1995), Integrating geographical information systems and multiple criteria decision making methods, *International Journal of Geographical Information Systems*, Vol. (9), No. (3), pp. 251-273.
17. Lin, H. Y., and Kao, J.J., (1998), A vector-based spatial model for landfill siting, Journal of Hazardous Materials, Vol. (58), Issues (1–3), pp. 3–14.
18. Longdill, Peter C., Healy,Terry R. and , Black, Kerry P., (2008), An integrated GIS approach for sustainable aquaculture management area site selection, *Ocean & Coastal Management*, Vol. (51), pp. 612-624
19. Longely, P. A., Goodchild, M., Maguire, D. J., and Rhind, D. W. (2001). Geographic information systems and science. Chicester, England, Wiley.
20. Madrucci, Vanessa, Fabio Taioli, and Carlos Ce´sar de Arau ´jo, (2008), Groundwater favorability map using GIS multicriteria data analysis on crystalline terrain, Sa ˜o Paulo State, Brazil, *Journal of Hydrology*, Vol. (357), pp. 153-173
21. Malczewski, J. (1999). GIS and Multicriteria Decision Analysis. New York, John Wiley.
22. Malczewski, Jacek, (2004), GIS-based land-use suitability analysis: a critical overview, *Progress in Planning*, Vol. (62), pp. 3–65
23. Shatnawi, G., (2006), Determine the Best Sites for Water Harvesting Projects (Dams & Hafirs) in Northeastern Badia Using GIS Applications, Unpublished M.Sc. thesis, Al Al-Bayt University, Jordan.
24. WAJ (Water Authority of Jordan), (2013), Jordan Water Sector Facts and Figures, Amman, Jordan.
25. Yalcin, Ali, (2008), GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): Comparisons of results and confirmations, *Catena*, Vol. (72), pp.1 –12.