Understanding of Morphometric Features for an Adequate Water Resources Management in Arid Environments

Mohamed Elhag*[1], Hanaa K. Galal[2,3], and Haneen Alsubaie[2]

[1]Department of Hydrology and Water Resources Management, Faculty of Meteorology, Environment & Arid Land Agriculture, King Abdulaziz University Jeddah, 21589. Saudi Arabia.

[2]Biological Sciences Department, Faculty of Science, King Abdulaziz University, Jeddah 21589. Saudi Arabia.

[3]Botany Department, Faculty of Science, Assiut University, Asyut, Egypt

Correspondence email: melhag@kau.edu.sa

Abstract

The current research investigates the significance of remote sensing data to evaluate the fluviological features and to identify the morphometric parameters of Yalamlam basin, West of Saudi Arabia. Hydrological characteristics, such as topographic parameters, drainage attributes, and the land use, land cover pattern were evaluated for the water resource management of the watershed area. Under GIS environment, the delineation of the watershed and the calculation of morphometric characteristics using ASTER GGDEM was undertaken. The drainage density of the basin has been estimated to be very high which indicates that the watershed possesses high permeable soils and low to medium relief (Hadley and Schumn 1961). The stream order of the area ranges from first to sixth order showing semi dendritic and radial drainage pattern that indicates the heterogeneity in textural characteristics and is influenced by structural characteristics in the study area. The bifurcation ratio (Rb) of the basin ranges from 2.0 to 4.42 and the mean bifurcation ratio is 3.84 of the entire study area that signifies that the drainage pattern of the entire basin is much more controlled by the lithological and geological structure. The elongation ratio is 0.14, which indicates that the shape of the basin belongs to the narrow and elongated shape. Land

Commented [R.1]: Unnecessary text

Commented [R.2]: Are essential to evaluate

Commented [R.3]: In the current study use and land cover map were generated by using Landsat-8 image acquired on August 10th 2015 was classified to distinguish mainly the alluvial deposit from the mountainous rock. The study reveals that hydrological evaluation using ASTER GGDEM is more precise and applied with compared to other techniques at the watershed scale.

Keywords: Hydrological characteristics, Morphometric characteristics, Remote Sensing and GIS techniques, Wadi Yalamlam, Watershed management.

1. Introduction

The choice of an optimal interpolation method, for the prediction of soil properties at unsampled locations, is a subject of great importance in agricultural management studies. Several attempts had been made in order to specify the most accurate interpolation technique for the generation of continuous soil attributes surfaces.

Most of the soil studies using interpolation techniques include the Inverse Distance Weighted and Kriging methods. The accuracy of these methods has been compared in several studies. Gotway et al. (1996) found that the IDW method generated more accurate results for mapping soil organic matter and soil NO_3 levels. Wollenhaupt et al. (1994) compared these two interpolation techniques and concluded that IDW was more accurate for mapping P and K levels of soil. Mueller et al. (2004) observed that for the optimal parameters of the method, the accuracy of IDW interpolation generally equaled or exceeded the accuracy of kriging at each scale of measurement. On the other hand, other researchers observed Kriging to be more accurate for the interpolation of soil attributes. Leenaers et al. (1990) found Kriging interpolation method the most accurate in comparison to IDW, for mapping soil Zn content.

Commented [R.4]: Delete
Commented [R.5]: was
Commented [R.6]: and was
Commented [R.7]: please rephrase
Commented [R.8]: unnecessary text
Commented [R.9]: rephrase
Commented [R.10]: scholarly work

Other studies compared Kriging IDW and Radial Basis Functions interpolation techniques in soil science. Schloeder et al. (2001) observed that Ordinary kriging and inverse-distance weighting were similarly accurate and effective methods, while thin-plate smoothing spline with tensions was not. Weller et al. (2007) resolved that not only the predications for kriging were not satisfied the kriging method, but also was as good as any other radial base function interpolation.

Commented [R.11]: additional

Since the early decades of the century, spatial variability of soil properties has been widely studied in order to understand the behavior of soils for agricultural purposes. Knowledge, of spatial variability and relationships among soil properties, is important for the generation of soil maps for reasons of land management.

Commented [R.12]: unnecessary text

Hydrological parameters are essential for adequate water resources management plans. Morphometric characteristics aim to investigate the watershed delineation, site selection in water recharge and discharge, run off modelling and other geomorphological studies (Sreedevi et al., 2013; Elhag, 2015). GIS helps a wide variety of basin characterization and evaluation applications under different terrain conditions (Pankaj and Kumar, 2009; Magesh et al., 2011).

Digital Elevation Model (DEM), such as ASTER GDEM (USGS, USA) is the keystone involvement in various extractions of Geo hydrological parameters of the watershed. Several parameters including slope, aspect, stream network, and upstream flow areas can be conducted from the DEM characterization (Grohmann et al., 2007; Elhag, 2015). Reliable results of implementing Remote sensing and GIS based morphometric evaluation using ASTER GDEM data have been reported in numerous scholarly work of watershed characterization (Farr and Kobrick, 2000; Panhalkar, 2014; Elhag, 2015). Author’s refers that ASTEDR GDEM is more useful and very accurate tool for the watershed delineation and morphometric evaluation for the watershed management.

Commented [R.13]: unnecessary text

The conducted results of the current study discuss that the analysis of methodical information and further hydrological and morphometric investigation can find out satisfactory alternative strategies for adequate rainwater harvesting based on observed calculations in the designated study watershed. The main aim of the present study is to identify and investigate various drainage attributes to geometrical evaluation of Yalamlam basin for the sustainable rainwater harvesting management and conservation of water resources.

Commented [R.14]: misplaced, its good for conclusion

2. Materials and Methods

2.1. Study Area

Wadi Yalamlam basin is located about 125 km southeast of Jeddah city and is bounded by latitudes 20° 26′ and 21° 8′N and longitudes 39° 45′ and 40° 29′E (Figure 1). Wadi Yalamlam basin drained large catchment area of about 180,000 hr. The basin boundary of the lower part is enlarged to include nearly all the flat area in the downstream part. Wadi Yalamlam basin is initiated from high elevation Hijaz escarpment with mean annual rainfall of about 140 mm. The basin elevations are greatly varies from upstream and downstream parts and range between 2850 m and 25 m (a.s.l.) respectively. The main course of Wadi Yalamlam is crosscut the highly fractured granitoids, gabbroic and metamorphic rocks until the coastal plain of the Red Sea. The upper and middle parts of Wadi Yalamlam basin are covered by intense natural vegetation. The lower part is covered mainly by Quaternary deposits and sand dunes with small-scattered highly altered granitoids and metamorphosed basaltic hills. Several basic dykes are recorded in the lower part of Wadi Yalamlam basin. The thickness of Quaternary wadi deposits increased in the lower part (Elhag and

Bahrawi 2017). Regional groundwater flow drains toward the south and southwest following the general trend of the main wadi channel. The gradient of the water table varies from one area to another according to the variations in the pumping rates and hydraulic properties of the aquifer. It has an average value of about 0.011. The high pressure of the subtropical zone in addition to local topography affects climate in Yalamlam basin. Both regional and local circulations have a dominant influence on the climate of the region. From the temperature records in the Red Sea coast stations, the mean monthly maximum temperature is 38ºC and the mean monthly minimum temperature is 20ºC. The highest recorded temperature in July is 49ºC and the lowest in January is 12ºC. The maximum mean monthly evaporation value is around 500 mm in summer, where in winter it is about 200 mm (Elhag, 2016)

Commented [R.15]: please rephrase

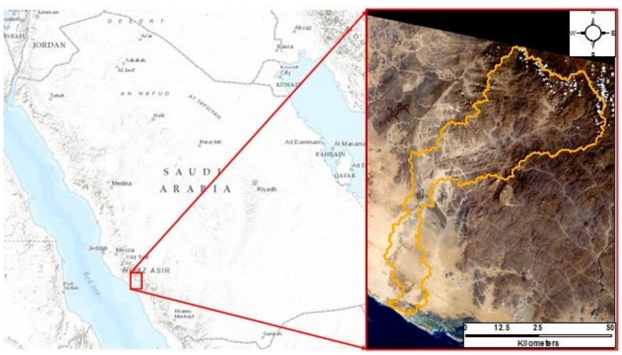

Figure 1. Location of the study area (Elhag 2016).

2.2. Soil sampling

Map accuracy and quality depends on the sampling method to be used, scale, analytical laboratory errors and prediction errors. Sampling approaches depend on the objectives of the study that are highly correlated to scale. Random Stratified Sampling was the adopted sampling design, the

Commented [R.16]: delete

landscape is divided into smaller areas, named strata, and afterwards 150 random samples are taken from the designated study area.

Commented [R.17]: please support your chosen sampling technique by 1 citation or more

2.3. Physical and Chemical soil analysis

Each individual sample was analyzed separately and each measurement was repeated three times for the same extract. Thus, the final values of the measured attributes are represented by the mean value of nine measurements. Soil samples were analyzed in order to estimate physical analysis (clay, silt and sand) and chemical analyses (pH, Calcium Carbonate, Electric Conductivity, Minerals and Organic Content) including all samples.

Commented [R.18]: I think you mean three not nine

Commented [R.19]: analyses

Commented [R.20]: rephrase

Commented [R.21]: please omit

For standard particle size measurement, the soil fraction that passes a 2-mm sieve is considered. Laboratory procedures normally estimate percentage of sand (0.05 - 2.0 mm), silt (0.002 - 0.05 mm), and clay (<0.002 mm) fractions in soils. Soil particles are usually cemented together by organic matter; this has to be removed by H_2O_2 treatment. However, if substantial amounts of $CaCO_3$ are present, actual percentages of sand, silt or clay can only be determined by prior dissolution of the $CaCO_3$.

The chemical procedures presented here are extensive, though by no means exhaustive. For any given element, there are several procedures or variations of procedures can be found in the literature (Walsh and Beaton, 1973; Westerman, 1990). Procedure for determining soil pH in a 1:1 (soil: water) suspension was after McLean (1982). The methodology of EC measurement is given in USDA Handbook 60 (Richards, 1954). Active $CaCO_3$ is usually related to total $CaCO_3$ equivalent, being about 50% or so of the total value. Total $CaCO_3$, is currently estimated after Drouineau (1942).

Commented [R.22]: there are no need for any chemical analysis as its not taken any part of the results part of the discussion part

2.4. Interpolation techniques

Geostatistics interpolation is based on the assumption that all values of a variable that is measured are the result of a random process. The phrase "random process" does not indicate that all events are independent. More specifically Geostatistics is based on random processes with dependence, otherwise called autocorrelation, and relies on some notion of replication. Repeated observations in nature can result in understanding the variation and uncertainty of natural phenomena, and furthermore in estimating their sequence in space and time. Three interpolation techniques were used for the generation of the prediction maps (interpolation). Inverse Distance Weighted (IDW), Radial Basis Function (RBF) and Ordinary Kriging (OK) method were compared according to the accuracy of the results.

Commented [R.23]: ,

Commented [R.24]: Techniques are

Commented [R.25]: Add citation

Spatial distribution equation (Weibel, 1997):

$$\gamma_{(k)}=\frac{1}{2\ x\ n(k)}\ x\ \sum_{i=1}^{n(k)}[Z(X_i)-Z(X_{i+k})]^2$$

Where: *n(k)* - number of pairs of observation; $Z(x_i)$ - soil property measured in point *x*, and in point $x + k$.

Interpolation equation (Stoer and Bulirsch,, 1980)

$$Z\ x\ (X_o) = \sum_{i=1}^{n} \lambda_i\ \ x\ Z(x_i)$$

Where: $Z\ x\ (x_o)$ - interpolated value of variable *Z* at location X_o, $Z(x_i)$ - values measured at location xi, λi; - weighed coefficients calculated based on the semivariogram.

Trend and random error equation (Johnson and Riess, 1982)

$$Z(S) = \mu(S) + \varepsilon(S)$$

The symbol s stands for the location of the prediction location. *Z(S)* is the variable you are predicting (total extractable heavy metal concentration). *μ(S)* is the deterministic trend. *ε(S)* is the spatially-autocorrelated random error.

2.5. Morphometric parameters

Based on the foundation scholarly work of Horton (1945), Schumm (1963), Strahler (1964) and others, several morphometric parameters were performed and computed utilizing ASTER GDEM under GIS environment. Consequently, watershed delineation, stream network identification, drainage frequency, drainage density, shape, elongation ratio, circularity ratio and form factor were computed and evaluated using 30m spatial resolution of ASTER GDEM. The methodologies adopted for the evaluation and computation of morphometric features are given in Table 1.

2.6. Supervised classification

Remote sensing data was obtained from Landsat Operational Land Imager (OLI-8) which is acquired on June 10th, 2013. Typical atmospheric and radiometric corrections and spatial resolution enhancement were implemented for each band individually. Furthermore, supervised classification was implemented using Support Vector Machine (SVM) classifier for better classification results (Psilovikos and Elhag, 2013). The final step in the digital image analysis is the evaluation of the accuracy of the computer derived classification results. These results are often expressed in tabular form, known as a confusion matrix (Elhag et al., 2013). The SVM classifier is implemented as:

$$K(x_i, x_j) = tanh(g x_i^T x_j + r)$$

Where:

g is the gamma term in the kernel function for all kernel types except linear

r is the bias term in the kernel function for the polynomial and sigmoid kernels.

Table 1. Summary of the implemented morphometric features:

Item	Morphometric feature	Equation	Citation
1	Stream length (L_u)	Length of the stream	Horton (1945)
2	Stream length ratio (R_L)	$R_L = L_u/(L_u + 1)$	Horton (1945)

3	Form factor (F_f)	$F_f = A/L^2$	Horton (1945)
4	Drainage frequency (F_d)	$F_d = N_u / A$	Horton (1945)
5	Drainage density (D_d)	$D_d = L_u / A$	Horton (1945)
6	Drainage texture (T)	$T = D_d * F_d$	Smith (1950)
7	Bifurcation ratio (R_b)	$(R_b) = N_u/(N_u + 1)$	Schumm (1956)
8	Elongation ratio (R_e)	$R_e = D/L$	Schumm (1956)
9	Mean bifurcation ratio (R_{bm})	R_{bm}= average of bifurcation ratios	Strahler (1957)
10	Relief (R)	$R = H\text{-}h$	Hadley & Schumm (1961)
11	Relief ratio (R_r)	$R_r = R/L$	Schumm (1963)
12	Stream order (S_o)	Hierarchical rank	Strahler (1964)
13	Stream no	Order wise no of streams	Strahler (1964)
14	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$	Strahler (1964)
15	Circularity ratio (R_c)	$R_c = 4\pi A/P^2$	Strahler (1964)

Where
A =Area of the basin (km^2)
D_d =Drainage density
F_f =Form factor
F_s =Stream frequency
L =Basin length (km)
L_{sm} = Mean stream length
L_u+1= The total stream length of its next higher order u
L_u = The total stream length of order u
N_u+1= Number of stream segments of the next higher order
N_u = The no. of stream segments of order u
P =Perimeter (km)
R_b = Bifurcation Ratio
R_c =Circularity ratio
R_e =Elongation ratio
RL=Stream Length Ratio
T=Drainage texture
π=3.14

3. Results and Discussion

Quantitative evaluation of the watershed through the analysis of morphometric parameter can provide significant information about the hydrological characteristics of rocks, which are exposed within the basin. The nature of drainage of a basin reveals reliable information about the permeability of the rocks and the yield of the basin.

The ASTER GDEM has been collected with 30 m resolution and the GDEM has been used to generate watershed area, aspects and slope map of the basin. The drainage network of a basin depends on endogenous forces and exogenous forces. Geology and precipitation pattern of the study area. ASTER GDEM was used for preparing aspects, slope map of the basin. Areal, relief and linear aspects of the basin were analyzed under GIS environment. Currently a geospatial technology has been given more precise and accurate information through the evolution of morphometric parameter for the assessment of drainage watershed. GIS technology and satellite data have been used to formulate data on spatial deviations in drainage attributes. Therefore, drainage parameter provides a significant insight into hydrological characteristics, which is more important to develop the watershed management strategies (YanYun et al., 2014).

Commented [R.26]: Rephrase, unnecessary text

Evaluation of drainage characteristics and other morphometric parameter of Yalamlam basin has been undertaken to calculate the parameter and built topology of the basin. Different type of Arial and linear aspects and their characteristics has been calculated, these aspects are, basin area (A), basin length (L), basin perimeter (P), bifurcation ratio (Rb), elongation ratio (Re), circularity ratio (Rc), drainage frequency (Fd) and drainage density (Dd) etc.

3.1. Stream order (S_o) and stream no:

The lower Yalamlam basin encompasses through the basin mega fan, which is formed by ancient and modern radial drainage pattern in the designated study area. The channel of this area is characterized by higher sinuous, decreased widths and lesser discharge capacity as a numerous traverse Paleo alluvial channels (Bahrawi et al., 2016). Therefore, the stream ordering of the study area has been ranked based on Strahler (1964) method and demonstrated in Table 2.

Table 2. Stream network order based on Strahler method.

	Strahler	Cnt_Strahler	Rb	Nu-r	Rb * Nu-r	Sum_Length
	1	598				872.847
	2	135	4.42963	733	3246.919	452.488
	3	22	6.13636	157	963.409	237.306
	4	6	3.66667	28	102.667	112.047
	5	2	3.00000	8	24.000	54.635
	6	1	2.00000	3	6.000	58.259
Sum		764	19.232659932	929	4342.99427609428	1787.582302
Mean			**3.847**		**4.675**	

3.2. Bifurcation ratio:

The bifurcation ratio was calculated by the no of streams of an order to the no of the streams of the next higher order. The values vary from 2.0 to 4.42 of the Yalamlam streams basin, which is also signified the maximum structural influences (Strahlar, 1964). After the calculation of bifurcation ratio, calculate the average value which is the mean bifurcation ratio is 3.84 of the basins. The value also indicates that the drainage pattern has been affected by structural disturbances within the basin. The obtained no of bifurcation ratio varies from one order to another order. Such variation is interpreted as irregularities of the lithological and the geological development within the watershed. The values of bifurcation ratio and mean bifurcation ratio have been shown in Table 3.

3.4. Drainage texture and drainage density:

Drainage density is an expression of spacing and distribution of channels as proposed by Horton (1932) that measure the total length of the streams of all orders as calculated with per unit area. Relative relief and slope gradient of the river basin primarily control the stream density. The stream density of the watershed has been calculated which is shown in Table 3. The value of drainage density is 0.92 in the study basin. The drainage density has been classified into five kinds of drainage texture as proposed by Smith (1950).

The drainage density more than 8 indicates very fine, the value 8-6 is fine, between 6-4 is moderate, the value 4 to 2 is coarse and less than 2 represent very coarser drainage texture. The observer drainage texture is 0.138, signifies the resistant permeable rock with moderate infiltration rate and moderate relief (Bahrawi et al., 2016). The value of the variation of drainage texture depends on different kind of natural factors that is rainfall and other climatic characteristics, rock, soil type, vegetation characteristics, permeability, relief, infiltration capacity within the watershed. The relationship between the hydrological features and the geological structures is estimated to be with a high drainage density caused by the mountainous relief in the basin. The lower value of drainage density reveals that, the region is composed of permeable sub surface material, low relief, dense vegetal cover which results in the increase of more infiltration capacity in the basin. The value of high drainage density indicates mountainous relief, thin vegetation and impermeable sub surface material, highly resistant rock types in the river basin.

3.5. Drainage frequency:

Drainage frequency or stream frequency is calculated by the total no of streams per unit area of all stream orders that proposed by Horton (1932). The correlation value of drainage density and stream frequency is plays positive of the basin, which suggests that the no of streams, population has increases with the increase of drainage density. The observed value of stream, frequency is about of 0.34 for the watershed exhibits the highly positive connection with stream density that has been shown in Table 3.

3.6. Elongation ratio:

The elongation ratio is calculated by the ratio between maximum length of the basin and the diameter of a circle, which fitted in the same basin area, as proposed by Schumm, (1956). The elongation ratio value generally varies between 0.6 and 1.0 where a wide variety of geological condition and climatic characteristics has. According to Strahlar (1964) the values close to 1.0 represent the region belongs to very low relief with less structural influences and the value ranges from 0.8 to 0.6 are generally associated with much steep slope and high relief. The values of elongation ratio can be categorized into 3 groups, namely less than 0.7 indicates elongated shape, and 0.8 to 0.9 values represent the oval shape and more than 0.9 values represent the circular shape of the basin. So, the elongated ratio of the study area is 0.14 that suggests that the basin shape is belongs to the much more elongated type (Table 3) of the basin where structural influence is much all over the basin.

3.7. Circularity ratio:

According to Miller (1953) circularity ratio is the ratio between the area of a circle, which fitted in the basin perimeter, and the total basin area. Circularity ratio is much more influenced by geological structure, relief, slope, climate, frequency and length of stream and land use land cover within the basin. The basin circularity ratio is 0.08, which represents that the basin is strongly elongated and belongs to the heterogeneous geological structure and materials. The observed values also signify the high run off capacity and low permeable capacity of subsoil and sub-surface soil along the basin area (Table 3).

3.8. Form factor:

Horton (1932) defines the form factor as the ratio between the square of the basin length and basin area. The values of form factor represent the flow intensity of the study area. Generally, the elongation shape and the values of form factor have a negative relationship that means the smaller value indicates the more elongated shape of the basin. The values should always be not exceeds 0.7854, higher value of form factor represent the higher peak flows of a higher period. The observed value of form factor is 0.06 of the Yalamlam watersheds signifies the elongated shape of the basin (Table 3). Therefore, the lower values and elongated shaped basin indicates that the watershed belongs to the flatter peak flow of shorter duration.

Table 3. Wadi Yalamlam morphometric features

Parameters	Descriptions	Remarks
Basin area (km^2)	1940.3	The basin area is too large
Basin length (km)	60.56	Basin length is very high
Basin perimeter (km)	417	High basin perimeter
Elongation ratio	0.14	Elongated
Form factor	0.06	Elongated shape and flatter peak flow
Circularity ratio	0.08	Strongly elongated and heterogeneous geological structure
Drainage frequency	0.34	Low stream frequency
Drainage density	0.92	Drainage density is considerably high
Drainage texture	0.138	Highly resistant permeable rock with moderate infiltration rate

3.9. Relief and relief ratio if the watershed:

Relative relief is the difference between the highest and lowest elevation of the watershed. The relief ratio is the ratio between relative relief and the maximum length of the basin as proposed by Schumm, (1956). It can analyses the steepness of the basin and evaluate the intensity of erosion process of the study area. Here the relief ratio is 4.17, which indicated that most of the designated basin is situated along the mountainous rough slope and much narrower in the lower areas.

3.10. Slope map:

Slope is the ratio between horizontal and vertical surface, of a region, which can be expressed by the percentage and degree. It was found that the most of the area (upper middle part) of Yalamlam watershed comes under steep, very steep and very high steep slopes that indicate the area having a much mountainous topography. The main channel slope of the basin comes under gentle slope (0.042) which designed to flat topography and excellent for the ground water management through favoring for infiltration.

Commented [R.27]: delete

4. Geo hydrological Inferences from Morphometric Evaluation:

The classification of Remote Sensing data was to quantify the area of all alluvial deposits to the bare rock area within the designated study area as illustrated in Figure 2. Table 4 indicates that the area of the alluvial deposits is roughly equal to the bare rock area which means that the watershed is the watershed is likely to be used for rainwater harvesting (Elhag, 2014 and Elhag and Bahrawi 2014 a).

Table 4. Wadi Yalamlam land cover classifications

Land cover category	Area sq. km	Percentage (%)
Vegetation	82.7	4.26
Alluvial deposit	803.3	41.4
Bare rocks	1054.3	54.3
Total	**1940.3**	**100**

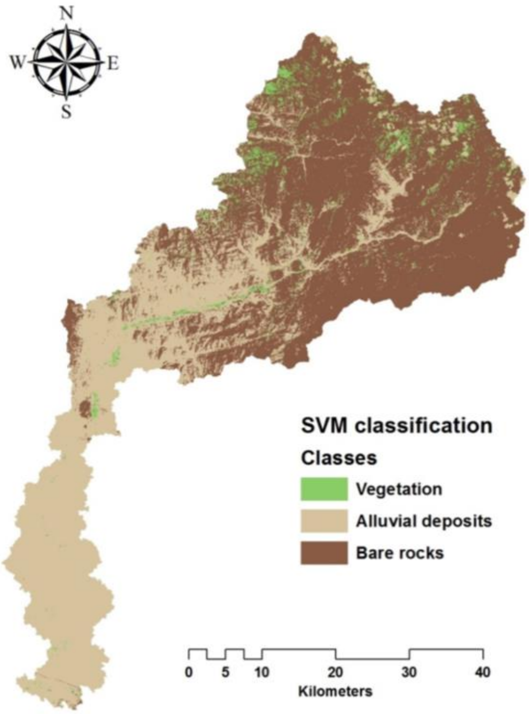

Figure 2. Supervised classification of Yalamlam basin.

Morphometric evaluation of the Yalamlam basin based on ASTER GDEM with remote sensing and GIS techniques is the most significant method for proper and precise interpretation of hydrological parameters of any terrain features. It is also indirectly influence the hydrological status of the basin. The quantitative morphometric evaluation has an intense utility to watershed delineation, water and soil conservation and their management for future sustainability. The morphometric analysis of the Yalamlam basin shows that the watershed has narrow, elongated shape and very high mountainous relief. The planning for runoff and artificial recharge of the area has been selected based on small-scale topographical maps and low relief (gentle slope) in the

Commented [R.28]: unnecessary text

lower area of the basin. Also drainage morphometric makes a positive role through GIS and remote sensing techniques by selecting artificial recharge sites and the creation of demand storage point in the mountainous region with the basin. In addition, if the morphometric information is integrated with other hydrological parameter of the river basin, the strategy for water harvesting and recharging measures gives a better plan for groundwater management and development for the future.

The drainage pattern of the basin is sub dendritic and radial in nature. The pattern was affected by more or less heterogeneous structural and lithological characteristics. In addition, high drainage density is observed all over watershed along with very high relief and impermeable subsoils and land rock substratum, mountainous terrain slope. On the other hand, lower riparian areas are low drainage density, which are favorable for the identification of water storage areas and ground water potential zones. However, slope plays a significant role in determining the relation between infiltration rate and runoff velocity where infiltration rate is inversely controlled by regional slope. So all evaluated parameters are more important to the analysis of future water availability of the study region.

Results obtained from pervious scholarly work of Şen, (1995) pointed out that the average transmissivity values calculated within the study area range from 91 to 147m^2/day. While the the transmissivity values increase sharply in the downstream area to range between 267 and 731 m^2/day (average 500 m^2/day). Such findings support the hypothesis that the aquifer is of high potential therein. On the other hand, the hydraulic conductivity values calculated for Yalamlam basin attain a high hydraulic conductivity (16 m/day) due to more permeable alluvial deposits (Sen, 1995, Elhag and Bahrawi 2014 b,c).

5. Conclusions:

The evaluation of hydrological characteristics of the Yalamlam watershed confirms that the area is having high relief and the shape is elongated in nature. The stream network of the watershed is basically dendritic type in lower portion which indicates the lack of structural influences and the homogeneity of textural characteristics, but the upper portion of the watershed highly influenced by tectonic and structural activity due to the parallel pattern of the drainage network. The drainage characteristics of the basin help to understand the different kind of terrain parameters, i.e, runoff, infiltration capacity and nature of the bedrock etc. The drainage density and frequency of the drainage basin is low that indicates the high permeability rate and well-drained capacity of the sub surface formation. All kinds of basic and derived parameters reveal an important the water recharge areas and measures can be undertaken for the soil conservation structures and water resource management. Therefore, watershed analysis using remote sensing data, GDEM data and GIS techniques has an efficient, precise tool for the understanding of any terrain attributes such as surface runoff, nature of bedrock, and infiltration capacity helps to better understanding of drainage evolution and management of ground water potential and status of landform and their characteristics for watershed management and planning. The study will be useful for water as well as natural resource management of any terrain at the watershed level. For sustainable water resource management and watershed development decision makers and planners can be used these kinds of hydrological analysis.

The thickness of the saturated zone within the aquifer varies from less than 1 m upstream of Yalamlam to about 30 m in the Sa'diyah area. The aquifer is generally unconfined, especially in the upper parts of the wadi. Semi-confining conditions may exist in the lower parts where layers of clay exist. There are about 31 wells in the basin of Wadi Yalamlam, out of which, 23 are hand-dug wells and the others are drilled.

Commented [R.29]: this paragraph is misplaced it should be rephrased and moved to study area description

Acknowledgement

This article was funded by the Deanship of Scientific Research (DSR) at King Abdulaziz University, Jeddah. The authors, therefore, acknowledged with thanks DSR for technical and financial support.

References

Bahrawi, J. A., Elhag, M., Aldhebiani, A. Y., Galal, H. K, Hegazy, A. K. and Alghailani, E. (2016). Soil Erosion Estimation Using Remote Sensing techniques in Wadi Yalamlam basin, Saudi Arabia. Advances in Materials Science and Engineering, DOI.org/10.1155/2016/9585962.

Drouineau, G. (1942). Dosage rapid du calcire actif du sol. Nouvelles donnes sur lareportation de la nature des fractions calcaires. Annual Agronomy, 12: 411 - 450.

Elhag, M. (2014). Remotely sensed vegetation indices and spatial decision support system for better water consumption Regime in Nile Delta. A case study for rice cultivation suitability map. Life Science Journal, 11(1): 201-209.

Elhag, M. (2015). Characterization of a Typical Mediterranean Watershed Using Remote Sensing Techniques and GIS Tools. Hydrology: Current Research, 6(1): 197-204.

Elhag, M. (2016). Evaluation of Different Soil Salinity Mapping Using Remote Sensing Techniques in Arid Ecosystems, Saudi Arabia. Journal of Sensors, 2016: 96175-96175.

Elhag, M. and Bahrawi, J. (2014a). Cloud Coverage Disruption for Groundwater Recharge Improvement Using Remote Sensing Techniques in Asir Region, Saudi Arabia. Life Science Journal, 11(1): 192-200.

Elhag, M. and Bahrawi, J. (2014b). Conservational Use of Remote Sensing Techniques for a Novel Rainwater Harvesting in Arid Environment. Environmental Earth Sciences, 72(12): 4995-5005.

Elhag, M. and Bahrawi, J. (2014c). Potential Rainwater Harvesting Improvement Using Advanced Remote Sensing Applications. The Scientific World Journal, DOI: 10.1155/2014/806959.

Elhag, M. and Bahrawi, J. (2017). Realization of Daily Evapotranspiration in Arid Ecosystems Based on Remote Sensing Techniques. Geoscientific Instrumentation, Methods and Data Systems, 6: 1-10.

Elhag, M., Psilovikos, A. and Sakellariou, M. (2013). Detection of Land Cover Changes for Water Recourses Management Using Remote Sensing Data over the Nile Delta Region. Environment, Development and Sustainability, 15(5): 1189-1204.

Farr, T. G. and Kobrick, M. (2000). Shuttle radar topography mission produces a wealth of data. American Geophysical Union, 81: 583–585.

Gotway, C. A., Ferguson, R. B., Hergert G. W. and Peterson, T. A. (1996). Comparison of kriging and inverse distance methods for mapping soil parameters. Soil Science Society of America Journal, 60: 1237-1247.

Grohmann, C. H., Riccomini, C. and Alves, F. M. (2007). SRTM-based morphotectonic analysis of the Pocos de Caldas alkaline Massif, southeastern Brazil. Computers and Geosciences. 33: 10–19.

Hadley, R. F. and Schumn, S. A. (1961). Sediment sources and drainage basin characteristics in the upper Cheyenn River Basin. US Geological Survey. Water supply paper, 1531-B: 137-97.

Horton, R. E. (1945). Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. U.S. Geological Survey Professional, p.282A.

Horton, R.E. (1932). Drainage basin characteristics. Trans. Amer. Geophys. Union 13, 350–361.

Johnson, L. W. and Riess, R. D. (1982). Numerical Analysis, 2nd ed. (Reading, MA: AddisonWesley), Chapter, 1.3.

Leenaers, H., Okx, J. P. and Burrough, P. A. (1990). Employing elevation data for efficient mapping of soil pollution on floodplain. Soil Use and Management, 6: 105-113.

Magesh, N., Chandrasekar, N. and Soundranayagam, J. (2011). Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach. Environmental Earth Sciences, 64: 373–381.

McLean, E. O. (1982). Soil pH and lime requirement. p. 199 - 224, In A. L. Page (ed.), Methods of soil analysis, Part 2: chemical and microbiological properties. American Society of Agronomy, Madison, WI, USA.

Miller, V. C. (1953). A Quantitative Geomorphologic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennessee, Project NR 389042, Tech Rept 3. Columbia University Department of Geology, ONR Geography Branch, New York.

Mueller, T. G., Pusuluri, N. B., Mathias, K. K., Cornelius, P. L., Barnhisel, R. I. and Shearer, S. A. (2004). Map Quality for Ordinary Kriging and Inverse Distance Weighted Interpolation. Soil Science Society of America Journal, 68: 2042-2047.

Panhalkar, S. S. (2014). Hydrological modeling using SWAT model and geoinformatic techniques. Egypt. The Egyptian Journal of Remote Sensing and Space Science, 17(2): 197–207.

Pankaj, A. and Kumar, P. (2009). GIS based morphometric analysis of five major sub-watershed of Song River, Dehradun district, Uttarakhand with special reference to landslide incidences. Journal of the Indian Society of Remote Sensing, 37: 157–166.

Psilovikos, A. and Elhag, M. (2013). Forecasting of Remotely Sensed Daily Evapotranspiration Data over Nile Delta Region, Egypt, Water Resources Management, 27(12): 4115-4130.

Richards, L. A. (1954). Diagnosis and improvement of saline and alkali soils. USDA Agric. Handbook 60. Washington, D. C.

Schloeder, C. A., Zimmerman, N. E. and Jacobs, M. J. (2001). Comparison of methods for interpolating soil properties using limited data. Soil Science Society of America Journal, 65: 470-479.

Schumm, S. A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersy. National Geological Society of America Bulletin, 67: 597-646.

Schumm, S. A. (1963). Sinuosity of alluvial rivers in the Great Plains. Bull. Geol. Soc. Am. 74, 1089–1100.

Sen, Z. (1995). Wadi Hyrdology. CRC Press, Taylor and Francis, New York.

Smith, K. G. (1950). Standards for grading texture of erosional topography. American Journal of Science, 248: 655-668.

Sreedevi, P. D., Sreekanth, P. D., Khan, H. H. and Ahmed, S. (2013). Drainage morphometry and its influence on hydrology in a semi-arid region: using SRTM data and GIS. Environmental Earth Science, 70 (2): 839–848.

Stoer, J. and Bulirsch, R. (1980). Introduction to Numerical Analysis (New York: Springer-Verlag), Chapter 2.

Strahler, A. N. (1964). Quantitative Geomorphology of drainage basins and channel networks. Handbook of Applied Hydrology; edited by V.T Chow (Newyork; Mc Graw hill) Section 4-11.

Strahler, A.N., (1957). Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union 38, 913–920.

Walsh, L. M. and Beaton, J. D. (1973). Soil testing and plant analysis. Soil Science Society of America, Madison. WI, USA.

Weibel, R. (1997). A Typology of Constraints to Line Simplification. In: Kraak, M. J. and Molenaar, M. (eds.): Advances in GIS Research II (7th International Symposium on Spatial Data Handling). London: Taylor and Francis, pp. 533-546.

Weller, U., Zipprich, M., Sommer, M., zu Castell, W. and Wehrhan, M. (2007). Mapping clay content across boundaries at the landscape scale with electromagnetic induction. Soil Science Society of America Journal, 71:1740–1747.

Westerman, R. L. (1990). Soil testing and plant analysis. 3rd ed. Soil Science Society of America, Madison, WI, USA.

Wollenhaupt, N. C., Wolkowski, R. P. and Clayton, M. K. (1994). Mapping soil test phosphorus and potassium for variable-rate fertilizer application. Journal of Production Agriculture, 7(4):441-448.

YanYun, N. I. A. N., Xin, L. I., Jian, Z. H. O. U., and XiaoLi. H. U. (2014). Impact of land use change on water resource allocation in the middle reaches of the Heihe River Basin in northwestern China. Journal of Arid Land, 6 (3), 273–286.