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Original Research

The impact of (DEM) accuracy on the watersheds areas as a function of spatial data

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abstract

Digital Elevation Model (DEM) is main input for watershed modelling. Recently, (DEM) is available online for free in different accuracies, and spatial resolutions as a product of several remote sensing satellites. Hence, it is necessary to find out which one is the best for watershed modeling in the study area. In this study, the different accuracies 30m spatial resolution DEMs of (Copernicus, SRTM, and ASTER) can be examined by using Remote sensing (RS) and Geographic Information systems (GIS) techniques to delineate and calculate the topographic characteristics for five different size and topography watersheds (Swaidy, Garlond, Khuwayr Hirah, Naqab, and Kalak) located on both sides of the Mosul reservoir in the northeastern part of Iraq. The analysis results can be led to find that the Copernicus (GLO-30) 30 m resolution DEM is the optimum and most accurate DEM in the selected study area at the vertical accuracy (1.3521 m) and with 95% confidence level is (2.6502 m) represented by the minimum Root Mean Square Error (RMSE) of the elevations differences between check points (MOWR elevations and LIDAR DEM 1 m resolution) and the used DEMs.
The watershed delineation and calculated topographic characteristics (watersheds boundary, elevations, area, perimeter and slope areas) are affected by DEM accuracy. Where the considerable accuracy of the differences is with the (Copernicus-SRTM) DEMS at the minimum RMSE of watersheds characteristics.

keywords: Digital Elevation Model, Remote Sensing Satellites, Geographic Information System, watershed delineation, topographic characteristics.

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1. Introduction

A watershed is a landform of a basin defined by ridgelines and highpoints that slope into stream valleys and lower elevations. A watershed, in other terms, is a geographical region that includes a common collection of rivers and streams that all flow into a single bigger body of water, such as a lake, a larger river or an ocean. Watershed characteristics such as size, shape, slope, land use/land cover, and vegetation are significant variables that influence different aspects of runoff [1].The quality (accuracy and resolution) of primary input GIS data which is required for delineating watersheds and configuring the hydrologic simulation model, such as the digital elevation model (DEM) and the land cover/land use (LC/LU) map, may affect the simulation results [2].A digital elevation model (DEM) is a three-dimensional representation of the surface of a terrain generated from topography elevation data, it is a digital representation of the elevation of the land surface. with respect to any given reference datum [3] . The selection of (DEM) resolution is influenced by some factors, such as cost, accessibility, simulation time with reason, and user need, among others [4].
The output when using all the DEMs in watershed delineation will be considered with regard to several topographic characteristics (boundary, elevations, area, perimeter and slope areas).

1.1. Problem statement

Many studies use satellite data (DEM) with certain spatial resolutions and accuracy to define the area of watershed and simulate it. Most of the hydrological models employ input data such as topographic, where these data become available as products of many satellites in different resolutions, accuracies, and sources. There for, it is important to understand the effect of using satellite data from different sources and accuracies on watersheds with various topographic characteristics.

The variety of the source, accuracy, and spatial resolution for the satellites data raises several questions:

What are the effects of using the highest available online freely open source (DEM) original resolution with different accuracies and sources on the general topographic characteristics (boundary, elevations, area, perimeter and slope areas) of different watersheds in the study area?

What is the suitable available online freely open source satellite data (DEM) in the study area?

1.2. Objective of the research

The main goals of this thesis are:

Analyze the effects of using different source inputs of free Digital Elevation Model (DEM) for the highest original resolution to delineate and compute topographic characteristics (boundary, elevations, area, perimeter and slope areas) with different sizes and topography watersheds.

Define the best free satellite data (DEM) for selected watersheds.

Find the topographic characteristics (boundary, elevations, area, perimeter and slope areas) of Watersheds in the selected study area to be prepared for the water resources Specialists for calculating the water runoff discharge with these areas by the unit hydrograph procedure.

1.3. Study area description

The study area is located in the northeastern part of Iraq, in the Mosul reservoir about 60 Km north of Mosul City between latitude (36°38'0" to 37°5'0")north and longitude (42°5'0" to 42°52'0")east, Nineveh, Iraq, which is represented by five watersheds of varied characteristics on both sides of the Mosul reservoir (Swaidy, Garlond, Khuwayr Hirah) valleys on the west side, and (Naqab, Kalak) valleys on the east side, these watersheds are different in size, topography, and LC/LU as shown in Fig 1.

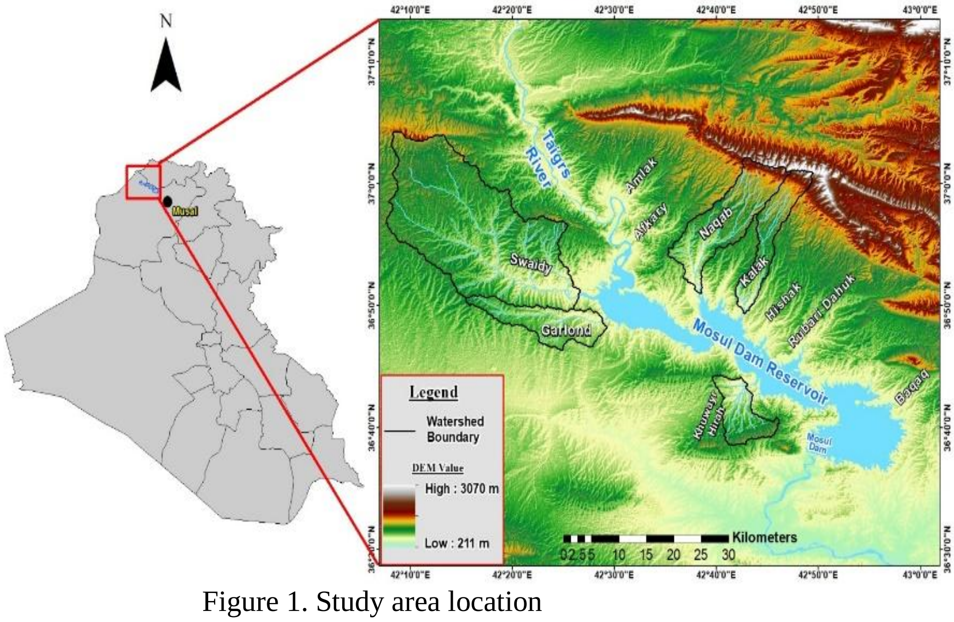

Figure 1. Study area location

The water in the reservoir comes from the Tigris River and ten side reservoir valleys, seven from the east side, and three from the west side of the reservoir [11]. The topography of the study area on the West side of Mosul reservoir is ranged from a flat arable area with a low slope rate for a Swaidy valley that reaches Qarachock Mountain in Syria. The Garlond valley is ranged from flat to mountainous, as for the Khuwayr Hirah Valley which is located within a mountainous area to reach Jamrok Mountain, a large proportion of unfit lands for agriculture. On the East side of the reservoir which is part of Duhok Governorate, there is a wide variation in elevation, the valleys of Naqab and Kalak begin with undulating, rugged lands near the lake, then gradually turn into arable lands and ending with mountainous lands in Bekher Mountain.

Geologically, the Pilaspi Formation is the oldest exposed formation in the Mosul reservoir's neighborhood, this formation's exposures are limited to hilly terrain. Dolostone, limestone, marl, and marly limestone make up the content. Fatha Formation and Injana Formation (both Lower–Upper Miocene) are exposed in the plains [12].The Land cover Seasonal crops (wheat and barley), vegetables, and pastures cover a large portion of the study area [13].

Climate of the study area shows significant seasonal variations in temperature and precipitation, which are characterized by dry in summer months and wet in winter months, the climate of the study area is close to that of the Mediterranean, with certain variations owing to the nature of the mountainous zone in Turkey. Summer seasons are hot and dry, while winter seasons are cold and rainy, with snowfall occurring on occasion in the mountainous areas. The rainy season begins in October month and continues until May month [14].

1 Material and methods

1.1. DEM sources and processing

The delineation and topographic characteristics of selected watersheds in study area are compared using three free available online different sources, and accuracy input DEMs with same spatial resolutions as shown in Table 1.

Table 1. The specifications of all downloaded DEMs used in watersheds delineation.

	SRTM (V3)	ASTER (GDEM V003)	Tan DEM-X Copernicus (GLO-30)
Data source	Space shuttle radar	ASTER Satellite	Tan DEM-X satellite
Generation and distribution	NASA/USGS	NASA/ METI	DLR / Airbus
Production method	C-band and X-band SAR Interferometry	VNIR nadir and backward viewing telescopes	radar satellite SAR Interferometry
Release year	2013	2019	2021 (for free)
Data acquisition period	11 days (in 2000)	2000 - 2013	2011-2014
Spatial Resolution	30 m	30 m	30 m
Horizontal reference	WGS84 _ellipsoid	WGS84 _ellipsoid	WGS84 _ellipsoid
Vertical reference	EGM96 _ Geoid	EGM96_ Geoid	EGM08_ Geoid
Vertical Absolute Accuracy (RMSE)	16 m (90% confidence)	20 m (95% confidence)	4 m (90% confidence)

1.2. Methodology

The overall research can be divided into several phases, as seen in Fig. 2.

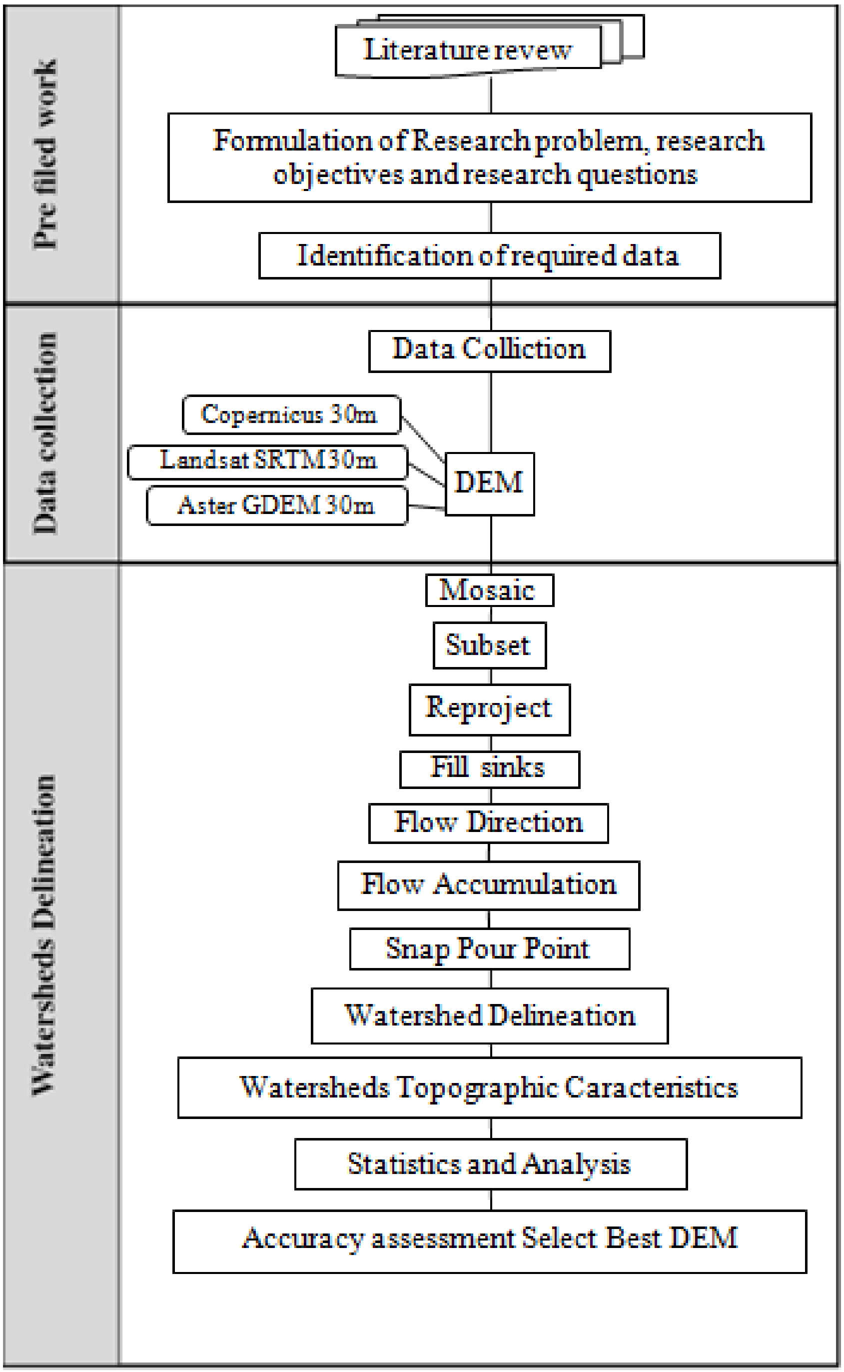

Figure 2. Flowchart of the research.

1.3. Watersheds delineation

The watersheds delineation was performed using (Copernicus DEM (30) m, SRTM DEM (30) m, and GDEM (30) m) data for various steps which were needed to transform the elevation data into flow direction and accumulation data, and finally into Watersheds. The specific tools needed for the watersheds delineation are found in the (ArcGIS Desktop 10.8) Hydrology tools within the Spatial Analyst toolbox, finally, the watersheds are delineated using the watershed tool in (ArcGIS Desktop 10.8) software, this operation takes into account the pour points, flow direction, and flow accumulation as shown in Fig. 3 to Fig. 5.

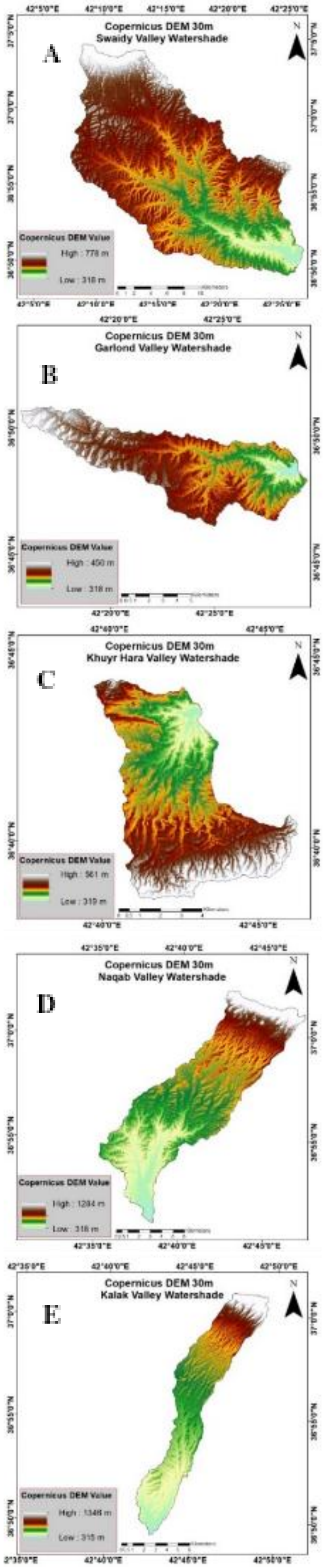

Figure 3. Delineated watersheds by Copernicus DEM (30) m

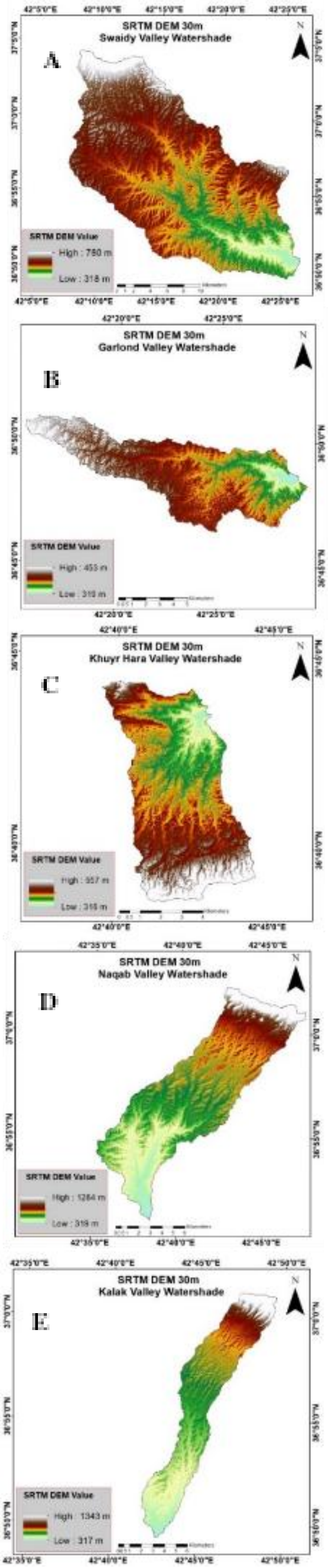

Figure 4. Delineated watersheds by SRTM DEM (30) m

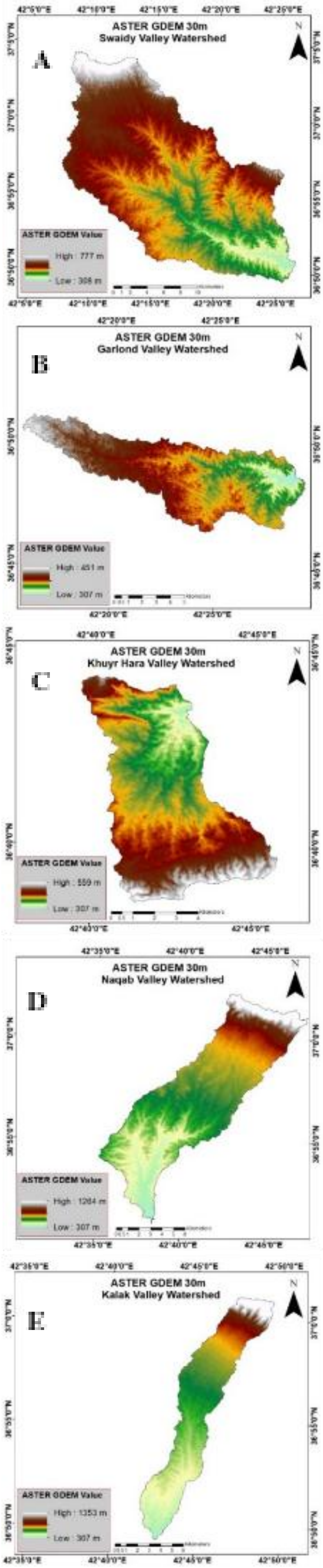

Figure 5. Delineated watersheds by ASTER GDEM (30) m

2 Results and discussion

2.1. Optimum DEM for the selected study area

For checking and selecting the best accurate DEM for the study area, (80) accurate elevation points were used, ((20) control points from Iraqi ministry of water resources (MOWR) fieldwork which gathered in (September/2020) at Mosul dam using (Topcon GPT-7501 total station, and Topcon Gr5 Gnss Receiver), and (60) point extracted from LIDAR DEM (1m horizontal resolution, 0.2m vertical accuracy with heights from ellipsoid WGS48) covering parts of the study area).

Selecting the best accurate DEM for the study area is done by comparing the elevations of 50 checkpoints with elevations interpolated from DEMs used in watersheds delineation (Copernicus DEM, SRTM, and Aster GDEM) at the same E/N coordinates after unified all heights to (EGM96). Relying on the elevation differences between checkpoints and used DEMs, the RMSE (root mean square error) and RMSE at 95% confidence level are calculated for differences as shown in Table 2.

Table 2. The RMSE results for the elevation differences between checkpoints and used DEMs

	R.M.S.E (m)	R.M.S.E (m) at 95%confidence level
Copernicus	1.3521	2.6502
SRTM	3.5985	7.0531
ASTER DEM	7.0491	13.8162

Depending on the analysis of the results, the Copernicus DEM have less RMSE and RMSE at 95% confidence level which means more vertical accuracy than the rest of DEMs in the study area (Landsat SRTM and Aster GDEM) respectively. Therefore the Copernicus DEM is optimum DEM for Watershed delineation and topographic characteristics Calculations for the selected study area.

2.2. Watersheds topographic characteristics analysis

Topography is an important land-surface characteristic that affects most aspects of the water balance in the watersheds [6].

The effect of different accuracies of used DEMs on different Watersheds Topographic characteristics such as (watersheds boundary, elevations, area, perimeter and slope areas) in the study area is analyzed.

2.2.1. Watersheds Boundaries

By comparing each delineated watershed from Copernicus DEM with the same watershed produced from other DEMs (SRTM and ASTER) through Intersect tool in (ArcGIS 10.8) software, and the Intersected (Coincided) areas are shown in Table 3. and Fig. 6.

Table 3. Coincided areas percentage between used DEMs for extracted watersheds

No.	Watershed Name	Copernicus versus SRTM DEM	Copernicus versus ASTER DEM
1	Suwaydy	99.41 %	98.95 %
2	Garlond	97.29 %	96.2 %
3	Khuwayrhirah	86.96 %	95.68 %
4	Naqab	99.60 %	99.04 %
5	Kalak	98.99 %	98.17 %
Average		**96.45 %**	**97.61 %**

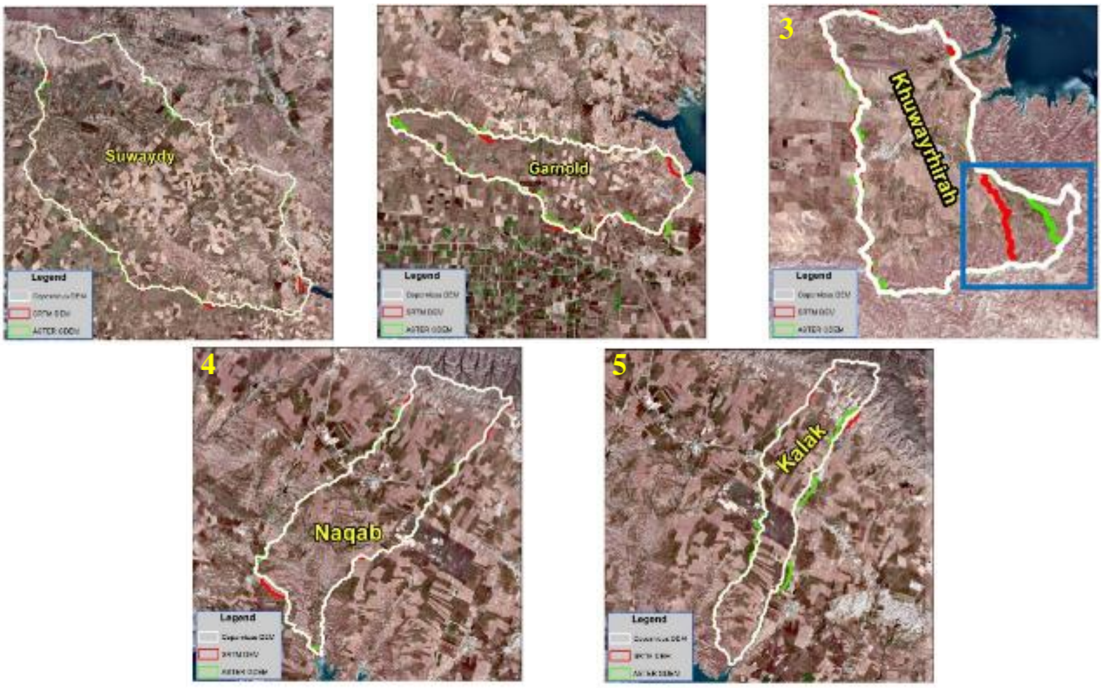

Figure 6. Delineated watersheds from different used DEMs

Based on the analysis of the results, in (Copernicus versus SRTM) DEMs all watersheds are more coincided areas percentage except the Khuwayrhirah watershed, the largest coincided area percentage (99.60 %) in Naqab watershed and the lowest coincided area percentage (86.96 %) in the south east of Khuwayrhirah watershed which is located within a rough mountainous area, and a large proportion is unfit for agriculture. This part of Khuwayrhirah watershed where the lowest coincided area which shown in in picture number (3) in Fig. 6 and Fig. 7 was analyzed, it was found that the reason for the large difference between borders is the variation in the topographic representation of used DEMs in this part of watershed as shown in Fig. 8 of profiles for cross section line (AA) which show the delineated watershed border as a point.

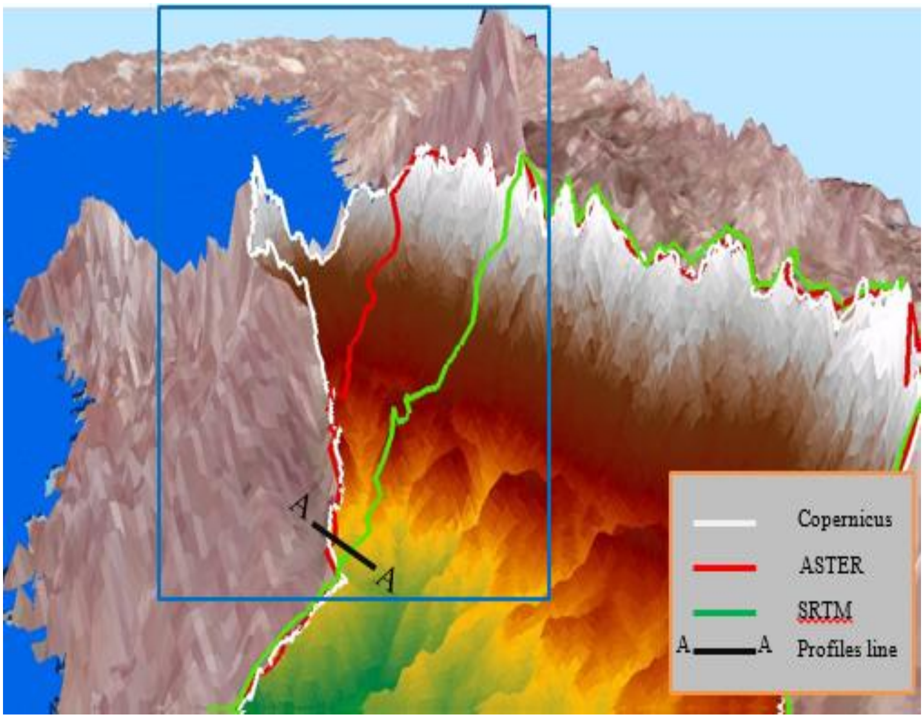

Figure 7. The lowest Coincided area part in south east of Khuwayrhirah watershed.

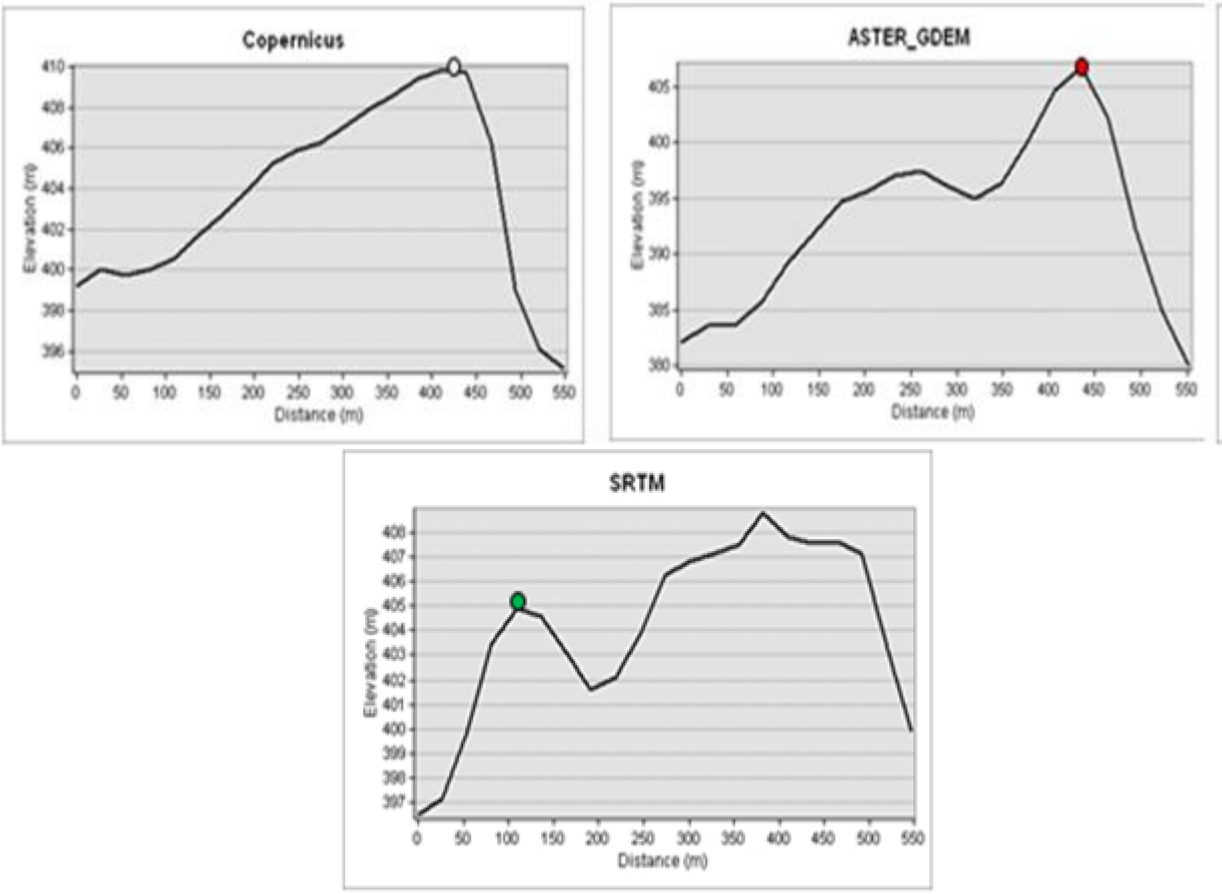

Figure 8. The variation in the topographic representation of used DEMs in the lowest Coincided area part of Khuwayrhirah watershed.

2.2.2. Watershed elevations comparison

The Minimum, Maximum, Mean, and Standard Deviation Elevations (St. Dev.) of each delineated watershed based on different used DEMs is calculated by generation of a report of statistics using (ArcGIS) software as shown in Table 4.

Table 4. Minimum, maximum, mean, and standard deviation of delineated watershed for used DEMs

No.	Watershed name	Copernicus DEM Elevations (m)				(SRTM) DEM Elevations (m)				Aster DEM Elevations (m)			
		Min.	Max.	Mean	St. Dev.	Min.	Max.	Mean	St. Dev.	Min.	Max.	Mean	St. Dev.
1	Suwaydy	318	778	548	133.08	318	780	549	133.66	308	777	542.5	135.68
2	Garlond	318	450	384	38.39	319	453	386	38.97	307	451	380.48	41.03
3	Khuwayrhirah	319	561	438.05	69.07	316	557	435.05	69.09	307	559	435.01	70.84
4	Naqab	318	1284	784.62	269.84	319	1284	782.1	267.79	307	1264	780.06	270.62
5	Kalak	315	1346	826.54	295.68	317	1343	827.03	294.21	307	1353	829.06	296.6

From this table there is no clear relationship between the elevations values and DEMs accuracy, by comparing the Minimum, Maximum, Mean, and Standard Deviation of Elevations of each delineated watershed from optimum DEM (Copernicus) with the same watershed can be produced from other DEMs (SRTM and ASTER GDEM). The differences of these elevations are calculated as shown in Table 5.

Table 5. Minimum, Maximum, Mean, and Standard Deviation Elevations differences

No.	Watershed name	Elev. Diff. (Copernicus-SRTM)				Elev. Diff. (Copernicus-ASTER)			
		Min.	Max.	Mean	St. Dev.	Min.	Max.	Mean	St. Dev.
1	Suwaydy	0	-2	-1	-0.58	10	1	5.5	-2.6
2	Garlond	-1	-3	-2	-0.58	11	-1	3.52	-2.64
3	Khuwayrhirah	3	4	3	-0.02	12	2	3.04	-1.77
4	Naqab	-1	0	2.52	2.05	11	20	4.56	-0.78
5	Kalak	-2	3	-0.49	1.47	8	-7	-2.52	-0.92
R.M.S.E			**1.732**	**2.757**	**2.029**	**1.186**	**10.49**	**9.54**	**3.98**

Based on the analysis of the results, it is revealed that the considerable accuracy is for the (Copernicus - RTM) DEM differences with the lowest R.M.S.E for all watersheds in Minimum, Maximum and Mean of elevations differences, all watersheds have lowest differences for the (Copernicus - SRTM) except for Maximum elevations differences in Khuwayrhirah watershed which has a greater difference (4) while (2) in (Copernicus - ASTER), it is noticeable that the elevations accuracy of DEM affected by the vertical accuracy of used DEM.

2.2.3. Watersheds area and perimeter calculation

The area and perimeter of each delineated Watershed based on different used DEMs is calculated using ArcGIS software as shown in Table 6.

Table 6. Areas and parameters of each delineated watershed for used DEMs

No.	Watershed name	Copernicus DEM_30m		(SRTM) DEM 30m		Aster(GDEM) DEM 30m	
		Area (km^2)	Perimeter (km)	Area (km^2)	Perimeter (km)	Area (km^2)	Perimeter (km)
1	Suwaydy	424.064101	110.581284	422.961	113.168304	421.600135	121.788787
2	Garlond	76.948711	55.743247	75.72018	59.049554	74.560889	61.30956
3	Khuwayrhirah	52.627759	39.553239	47.97126	35.236752	49.80198	39.063948
4	Naqab	120.972282	66.89928	122.3607	67.796469	122.939525	70.036416
5	Kalak	68.688276	57.61337	69.09485	58.878046	70.832922	61.727953

From this table, except the Khuwayrhirah watershed, it is noticeable that the areas are directly proportional to DEM accuracy in the relatively flat watersheds (Swaidy and Garlond) and inversely proportional to DEM accuracy in the wide variation elevations watersheds (Naqab and Kalak), while the perimeters are inversely proportional to DEM accuracy in all watersheds except for Khuwayrhirah watershed , by comparing the watersheds areas and perimeters based on optimum DEM (Copernicus GLO-30) to the areas and perimeters based on SRTM and ASTER DEMs, the differences are calculated as shown in Table 7.

Table 7. Areas and perimeters differences

No.	watershed name	Diff.(Copernicus-SRTM)		Diff. (Copernicus-ASTER)	
		Area (km^2)	Perimeter (km)	Area (km^2)	Perimeter (km)
1	suwaydy	1.103	-2.587	2.464	-11.208
2	garlond	1.229	-3.306	2.388	-5.566
3	khuwayrhirah	4.656	4.316	2.826	0.489
4	naqab	-1.388	-0.897	-1.967	-3.137
5	kalak	-0.407	-1.265	-2.145	-4.115
R.M.S.E		**2.302**	**2.781**	**2.376**	**6.060**

From this Table, it seemed that the major accuracy is for (Copernicus –SRTM) DEM differences with lowest RMSE and differences of all watersheds areas and perimeters except the Khuwayrhirah watershed because of the difference in watersheds delineation and borders in the southeast part of this watershed. These results can be revealed that the areas and perimeters of watersheds are affected by the vertical accuracy of used DEM.

2.2.4. Watersheds land slope area calculations

For each watershed, the percentage of the land slope area is calculated as percent rise by using slope from spatial analyst tools in (ArcGIS Desktop 10.8) software, by reclassify tool all the results are reclassified to fit the wanted slope percentage. Then the zonal statistics as table tool used to summarize and extract the area with area percentage of every slope interval for each Watershed based on used DEM as shown in Table 8.

Table 8. Percentage of slope areas for each watershed based on used DEMs

DEM	No.	Watershed Name	(0-3)%	(3-6)%	(6-9)%	(9-12)%	(12-15)%	(15-20)%	(20-30)%	>30%
Copernicus	1	Suwaydy	22.36	43.17	20.19	7.91	3.27	2.06	0.76	0.28
	2	Garlond	55.66	35.52	6.11	1.77	0.37	0.3	0.21	0.06
	3	Khuwayrhirah	8.64	33.64	24.69	12.44	7.19	7	5.38	1.02
	4	Naqab	9.55	31.62	22.29	11.25	6.41	6.26	5.35	7.27
	5	Kalak	13.80	39.79	22.28	7.65	2.62	2.2	2.66	9
SRTM	1	Suwaydy	24.90	43.78	19.71	6.96	2.62	1.34	0.47	0.22
	2	Garlond	46.17	43.70	8.28	1.41	0.32	0.07	0.04	0.01
	3	Khuwayrhirah	13.14	32.45	24.58	13.10	7.15	4.71	4.59	0.28
	4	Naqab	13.11	32.74	21.76	10.71	5.99	5.35	4.21	6.13
	5	Kalak	18.72	39.89	19.73	6.59	2.37	1.96	2.58	8.16
ASTER_GDEM	1	Suwaydy	11.89	28.39	26.23	16.87	8.71	5.76	1.78	0.37
	2	Garlond	17.34	36.54	26.80	12.13	4.6	2.12	0.43	0.04
	3	Khuwayrhirah	9.49	25.11	24.34	16.31	9.51	8.2	5.71	1.33
	4	Naqab	8.46	21.56	22.38	16.05	9.74	8.76	6.26	6.79
	5	Kalak	32.75	39.45	13.80	3.54	1.63	2.36	4.1	2.37

From this table there is no clear relationship between the percentages of slope areas the accuracies of used DEMs, by comparing the slope areas Percentages of all watersheds for optimum DEM (Copernicus GLO-30) with extracted slope areas Percentages for SRTM and ASTER DEMs, the differences and R.M.S.E are calculated as showing Table 9.

Table 9. Percentage of slope areas Different and R.M.S.E

DEM	No.	Watershed Name	(0-3)%	(3-6)%	(6-9)%	(9-12)%	(12-15)%	(15-20)%	(20-30)%	>30 %
Diff. Copernicus-SRTM	1	Suwaydy	-2.54	-0.61	0.48	0.95	0.65	0.72	0.29	0.06
	2	Garlond	9.49	-8.18	-2.17	0.36	0.05	0.23	0.17	0.05
	3	Khuwayrhirah	-4.5	1.19	0.11	-0.66	0.04	2.29	0.79	0.74
	4	Naqab	-3.56	-1.12	0.53	0.54	0.42	0.91	1.14	1.14
	5	Kalak	-4.92	-0.1	2.55	1.06	0.25	0.24	0.08	0.84
	R.M.S.E		**5.543**	**3.741**	**1.532**	**0.759**	**0.365**	**1.158**	**0.639**	**0.715**
Diff. Copernicus-ASTER	1	Suwaydy	10.47	14.78	-6.04	-8.96	-5.44	-3.7	-1.02	-0.09
	2	Garlond	38.32	-1.02	-20.69	-10.36	-4.23	-1.82	-0.22	0.02
	3	Khuwayrhirah	-0.85	8.53	0.35	-3.87	-2.32	-1.2	-0.33	-0.31
	4	Naqab	1.09	10.06	-0.09	-4.8	-3.33	-2.5	-0.91	0.48
	5	Kalak	-18.95	0.34	8.48	4.11	0.99	-0.16	-1.44	6.63
	R.M.S.E		**19.693**	**8.872**	**10.360**	**6.964**	**3.604**	**2.223**	**0.905**	**2.976**

Based on the analysis of the results, it can be revealed that the considerable accuracy is for (Copernicus - STRM) DEM differences with the lowest RMSE of watersheds slope areas Percentages differences, which means these results are affected by the vertical accuracy of used DEM. The map of land slope for each watershed based on Copernicus DEM are shown in Fig. 9.

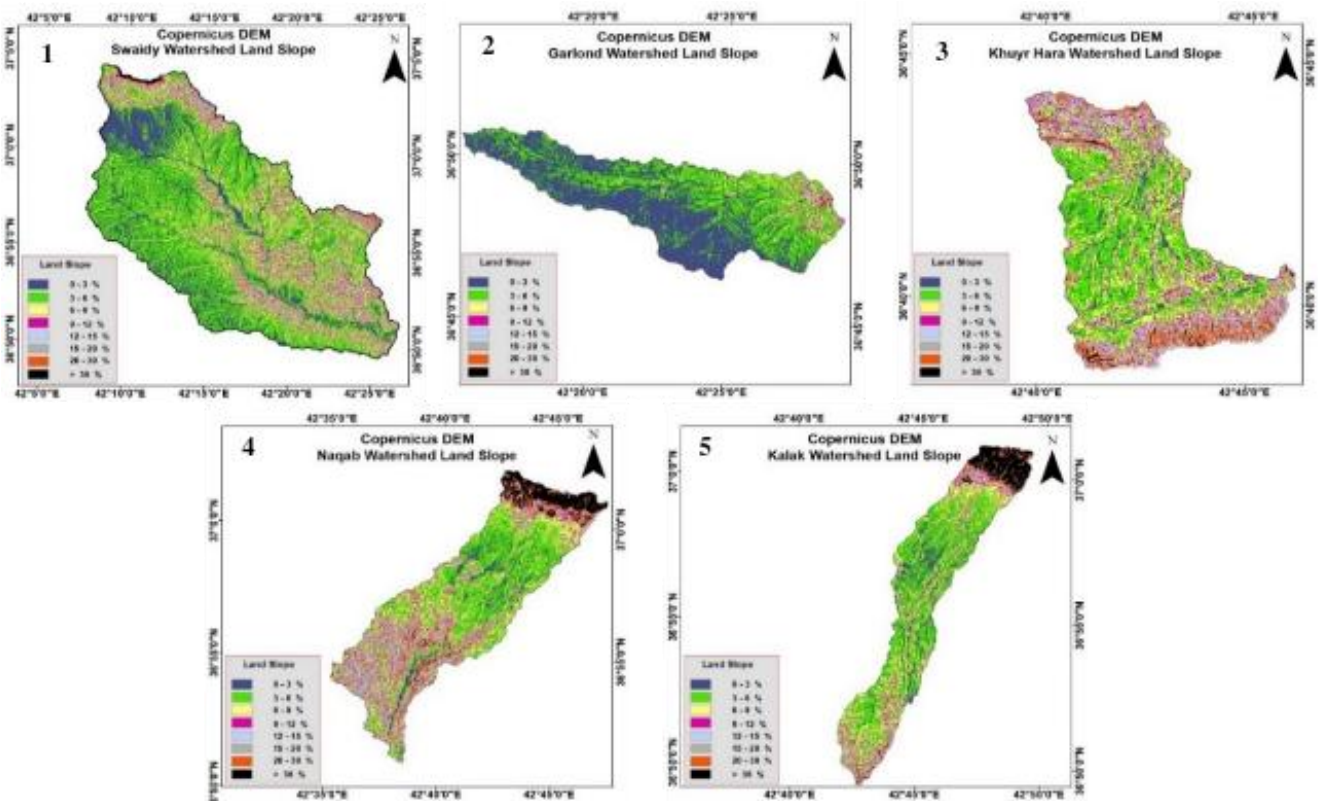

Figure 9. Land slope maps for watersheds based on Copernicus DEM.

3 Conclusions

From the results analyses of the experimental works, GIS techniques, and remote sensing processing works in the present study, the most important conclusions that indicated are given in the following:

- The Copernicus (GLO-30) DEM is the most accurate (30) m resolution with No charge DEM for the selected study area. Where, the RMSE results for the elevations differences between check points (MOWR elevations and Lidar DEM) and the used DEMs for the Copernicus (GLO-30) is (1.3521 m) and with 95% confidence level is (2.6502 m). Therefore, it can be considered as the optimum DEM for watershed delineation and topographic characteristics calculations and comes after the Copernicus DEM in accuracy both the SRTM and ASTER DEMs, respectively.
- All the selected watersheds topographic characteristics (boundaries, area, perimeter, elevations and land slope area percentages) in the study area have least RMSE (more accuracy) in (Copernicus-SRTM) than in (Copernicus-ASTER GDEM), and all differences are least in (Copernicus-SRTM) for all watersheds except Khuwayrhirah watershed, so the topographic characteristics affected by the vertical accuracy of the used DEMs. Therefore, all the results can be came in proportion to the accuracy of used DEMs (Copernicus, SRTM, and ASTER) in all watersheds, while the reason for the large difference in delineation and other topographic characteristics in Khuwayrhirah watershed which is located within a rough mountainous area, and a large proportion is unfit for agriculture is the variation in the topographic representation between used DEMs in the southeast part of this watershed.

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