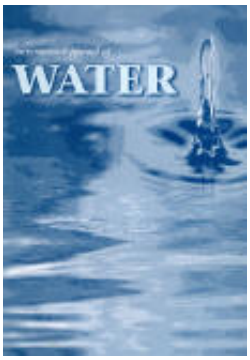

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Hydrological modelling of Usk River basin in the State of Wales, UK using geospatial technologies

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Abstract: The measurement and analysis of river basins is one of the basic tasks in morphometric studies, and it is extremely important for many geomorphological and hydrological applications. The current study aims to identify the hydrological characteristics of the Usk River basin in the State of Wales, United Kingdom, with boundaries (51°32′31″)N and (2°59′6")W. Digital elevation model (DEM) and Landsat 8 of the study area are downloaded and analysed hydrologically using geographic information systems (GIS). The results showed that the basin of the Usk River descends from an elevation of 879 m in the northeast at the city of Brecon (the source) to the southwest with an elevation of (–32 m) at the city of Newport (the estuary). The topographic wetness index (TWI) ranges between (5.5–7.5), and sometimes rises to range (15–25). The sediment transfer index (STI) indicates that the Usk River and its tributaries do not carry significant river sediments.

Keywords: hydrological modelling; Usk River Basin; geospatial technologies; GIS; geographic information systems; TWI; topographic wetness index; STI; sediment transfer index; State of Wales; UK.

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1 Introduction

Harvesting rainwater and torrential rains for valleys is one of the very old methods that humans have undertaken in many regions to benefit from it as much as possible. Water harvesting is a technique that is used to reserve and store rainwater in different ways according to the purpose of collecting it and its precipitation rates, and reusing it when needed, whether for drinking or supplementary irrigation or groundwater recharge (Al-Saadi and Al-Jabri, 2018). The high population inflation at the present time, which is accompanied by rapid urbanisation, in addition to the changes that occur in the global climate, which have led to irregular rainfall intensity, all of these factors led to difficulty in the process of managing the water sector at the level of storage and future plans. Various water resources play a fundamental role in the water sustainability sector, which requires evaluation at the regional and global levels in order to maintain appropriate livelihoods, a balanced economy, address the problem of drought early or at least predict it, and ensure the provision of food security at the local, regional and global levels. The techniques of geographical information systems (GIS) and remote sensing provided by satellite images because of the extremely important data that these images carry, are considered one of the promising tools in the study and interpretation of landscapes and the analysis of the hydrological system of the environmental, air and water systems, as the analyses of these satellite images can provide hydrological indicators through which water resources can be evaluated and managed (Gupta et al., 2014; Amjad and Safaa, 2022).

The river drainage basins are the stage on which the various geomorphological processes take place, through which we can identify their natural characteristics. Drainage basins in dry areas are usually exposed to sudden and irregular torrents, which exposes human areas to changing the uses of the basin land, such as removing vegetation, which increases surface runoff rates and decreases leakage rates. Therefore, it is necessary to prepare the measures that would ensure that the risks of floods are avoided as much as possible through the construction of dams or diverting the paths of valleys; other solutions focus mainly on estimating the amount of surface runoff and the size of the risks arising from it. Drawing and defining the boundaries of the main and secondary drainage basin is the basis for hydrological and geomorphological studies, as it is mainly used in estimating the base flow, runoff, and total flow. Hydrological parameters can be relied upon to estimate the size of the flood in the drainage basin during different periods of time, which is considered the main factor in the design of hydraulic engineering facilities for preventing the dangers of torrents and floods (Awawdeh, 2020).

Morphometric studies based on measurements and quantitative analysis have added a lot to geomorphological studies, especially in the field of river basin studies. The importance of the quantitative analysis of the geomorphological processes and the river network increased since the middle of the twentieth century, when Horton (1945) and Strahler (1964) dealt with the quantitative analysis of the geomorphological processes in the river basins and the water network, where Horton classified the tributaries, followed by Strahler by modifying the method of classifying river tributaries. Morphometric analysis also provides many quantitative data related to the various elements of the water network in terms of the type, shape and number of morphometric variables that enter into its composition. The use of morphometric analysis methods aims to increase information about the actual system of disparate drainage networks, and then try to reach useful

generalisations and laws governing the relationship between basins and watercourses by objective methods and mathematical methods (Ashraf, 2019).

Modelling is one of the most important modern sciences in geomatics science applications in general and applied geomorphology in particular. It is considered an abstraction of reality based on collecting information that serves the purpose of the research study. By analysing digital data, digital elevation models (DEMs), and satellite images, a lot of hydrogeological information can be extracted, and by relying on it, the necessary treatments can be provided for the water sector in particular. The two-dimensional hydrological modelling works aim to identify more accurately the areas endangered by runoff and classify them into categories according to the degree of danger and the extent of their impact on human installations, facilities and infrastructure that intercept the runoff path (Mona et al., 2020).

Satellite images can provide useful information for remote sensing devices, which in turn sense global spatial and temporal phenomena for any region and at different scales. Geomorphological parameters can be estimated with the help of hydrological modelling in which remote sensing data are included as dynamic basic elements and as effective and powerful tools to obtain important data pertaining to the studied area with periodic time periods and at a lower cost. Satellite images have spectra of different wavelengths and cover vast spatial areas, where as a result of the analysis of these images, physical difficulties related to time periods can be overcome. Digital models can be developed depending on the information provided by regional or global aerial images (Sahoo, 2013). Geographic information system (GIS) is an advanced and modern tool that has a superior and accurate ability to derive hydrological characteristics, based on digital elevation models (DEMs), thermal images (TM) and Landsat 8 images. Geographic information systems have developed in various fields and specialisations such as: urban planning, environmental protection, land use, facilities management, and others. Because of its ability to organise and analyse the geographical information, it has the ability to link spatial and descriptive data, as well as the ability to deal with several layers of data simultaneously. GIS uses spatial analysis tools, which is the application of analysis methodology in evaluating geographical features and the spatial relationships between them. It includes the location of the phenomenon, its distribution pattern, determining the level and quantity of spatial relationships between them, and analysing geographical surfaces and natural levels in terms of direction, inclination, and natural levels. Flow direction map, side map and flow arrangement map, drainage network and valleys maps, flow accumulation map, and many more hydrological parameters can be found by modelling, analysing and processing data stored in satellite images (Krysanova et al., 1999; Singh et al., 2013; Saleem et al., 2022). Maryline et al. (2012) studied Wadi Araba through evaluating the tectonic fault in the Quaternary era using the GIS program. Ali et al. (2009) studied the groundwater of Wadi Araba using the hydrological modelling of the GIS program. Pongput et al. (2013), Panhalkar (2014) and Dipti et al. (2018) studied river basins using the SWAT program. GIS has been widely used in extracting watershed basins and river basins through analysing the SRTM aerial images (Aravinda and Balakrishna, 2013; Bajirao et al., 2019; Mani and Kumar, 2020; Muhammad et al., 2015).

The aim of this study is to use modern technical methods in conducting spatial analyses through geomatics techniques and software, advanced analyses, digital elevation processing, drawing drainage networks, slope degrees, and inclination angles. It has been possible to identify the geomorphological characteristics of the Usk River Basin in the

State of Wales in the UK through the use of hydrological modelling provided by GIS based on DEMs and Landsat 8.

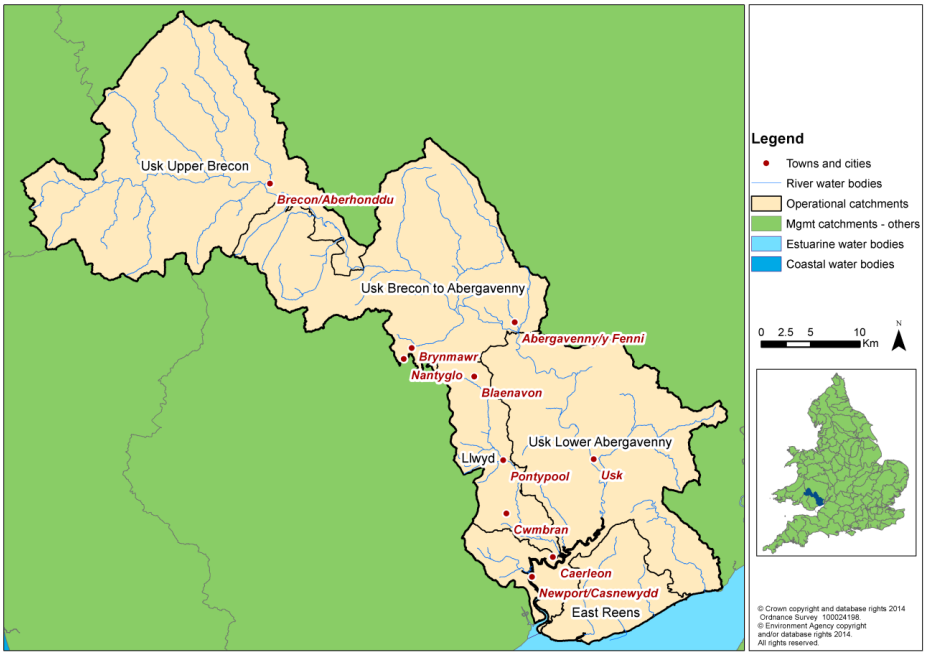
2 Area of interest (AOI)

The town of Usk is located in the State of Wales in the UK, within the geographical borders between longitude (51°32′31″)N and latitudes (2°59′6″)W. The Usk River is considered one of the largest rivers in it, and it is running with a variety of water levels, where in some areas the water level is close to the bottom, and in other areas the water depth is large and affected by the tidal phenomenon. The annual discharge rates are approximately equal to (27.919 m^3/s), as the minimum discharge is (1.58 m^3/s) and the maximum is (585.4 m^3/s). The Usk River serves vast areas of agricultural and residential lands with water. It flows from many long and narrow watersheds that pass through scenic landscapes for a distance of about 125 km as it rises up the slopes that lie north of Black Mountain and passes through the towns Crickhowell, Brecon, Usk and Abergavenny. The catchment terminates at the mouth of the River Usk at Newbridge, which descends towards the final mouth of the River Severn at Newport, as shown in Figure 1. The catchment includes the Gwent Levels south of the River Usk as well as the vast expanses of reclaimed grassland that lie on the coast and which It is considered one of the historical areas due to its preservation of nature. The watershed that branches off from the Usk River is rich in wildlife, including bullhead, lamprey and a wide variety of habitats, which are of high environmental value due to their national and international designations. The lands around the Usk River are mostly used for agriculture, while the western and northern highlands are characterised by sheep farming, the east and south lowlands with dairy and beef products, and mixed farmland with a variety of agricultural crops. As a result, pollution from rural areas constitutes one of the major threats to plants and wildlife located in the water environment of the Usk River watershed (Natural Resources Wales, 2016).

The watershed that branches off from the Usk River serves a large area of up to 1358 km^2, as these areas have a fluorescent geomorphological system characterised by a diverse geology of soils. The Usk River passes through three geological regions, and accordingly it is divided into three parts. The Upper Usk is located in the near part of the county of Carmarthenshire, where this region is characterised by being very high, reaching an altitude of approximately 500 m. The central part of the Usk River flows towards the northeast near the slope of the Brecon Beacons at the city of Abergavenny, as the width of the river in this region decreases to 3 m and the water height in it begins to decrease from 100 m to lower levels as it goes south. The third and final part is Lower Usk, as it represents the southern part of the river, in which the confluence takes place at the mouth of the Severn River in the city of Newport. In general, the Usk River flows on mudstone, marl, and sandstone, as the river bed is greatly affected by igneous sediments that result from the glacial state, as well as mud sediments. The Usk River crosses a series of ancient mudstone and limestone, and this series is called (Silurian Ludlow), which is characterised by its high resistance to weather conditions. This rocky chain is found in many places, and this in turn led to the establishment of a rocky water channel that branches out from the Usk River. The Usk River flows south, passing over mudstones, marls, and sandstones, until it crosses the Triassic Copper Marls at Newport Docks. The Usk River, from its source in Brecon to its estuary at its confluence with the

Severn River, runs over alluvial and glacial deposits with great depths, but despite the varying and complex geology of these deposits, they have little impact on the river. The lower part of the Usk River has a natural fluvio-geomorphic system, as the part of the river between Caerleon and Usk contains many meanders that pass perpendicular to the high land slopes. The lower section of the Usk River, which connects Abergavenny and Newport, is very complex as it passes through strong and steep outer slopes compared to the shallower slopes at its source. There are many lakes and back channels adjacent to the Usk River at various places along the river as it gains its drainage from the river through its flow in the floodplains and slopes (David, 2008).

Figure 1 Area of interest (AOI) (see online version for colours)



Source: As adopted by Natural Resources Wales (2016)

The weather in the town of Usk in Wales is characterised by being mostly cloudy, very cold and windy in winter, while in summer it is partly cloudy and comfortable due to the somewhat high temperatures. Summer temperatures range from (60–70)°F, which is equivalent to (16–21)C° in the months (June–August), while in the rest of the year they range from (37–55)°F, which is equivalent to (2.5–10)C°. Depending on tourism reports, the best tourist times to visit the town of Usk are in times of warm weather, which is from mid-June to early September. As for precipitation in the town of Usk, the rainy season usually lasts for four months, from October 5 to February 5, as the wettest month is November, while the dry season lasts for eight months, from February 5 to October 5, when the least humidity is the month of April. The most rainy month is November, with an average of no less than 11 days during the month, as it peaks at the end of October, with a rate of approximately 38% (https://weatherspark.com/y/39441/).

3 Methodology

Morphometric analysis provides many quantitative data related to the various elements of the water network in terms of the type, shape and number of morphometric variables that are included in its composition. The use of morphometric analysis methods aims to increase information about the actual system of disparate drainage networks, and then try to reach useful generalisations and laws governing the relationship between basins and watercourses by objective and mathematical methods. By using spatial modelling methods provided by remote sensing techniques (RS) and GIS, the morphometric and morphological characteristics of the study area will be found (Bashir, 2016).

The study relied on the analytical approach in order to analyse the digital data of satellite images, where the DEM for the study area will be downloaded from (http://earthexplorer.usgs.gov). Digital elevation model will be processed using Geographical Information System (GIS) software (Arc Map (10.2)). Also, the satellite image (Landsat 8) will be downloaded from (http://earthexplorer.usgs.gov) and soil data from (https://www.fao.org) to extract the soil map of the study site. By using the analysis tools (Spatial Analysis-Hydrology) provided by (GIS), the (DEM) image will be processed to extract the (Fill) image, which is one of the most important commands through which the DEM will be corrected from abnormal values. Accordingly, a visual (Direction Flow) will be produced by applying the analysis tool as each resulting cell represented the value of the flow direction in the adjacent cell. The ranks of the (Flow Accumulation) network will be extracted for the Usk River Basin. According to Strahler method, Stream Order of water discharge will be extracted. The main and subsidiary water basins of the Usk River Basin will be determined with the direction of the discharge and the ranks of its streams using spatial analysis commands included a final stage to address the errors of the drainage network, such as the secondary branches separated from the network, which give wrong results for the ranks of the streams. The other morphometric characteristics of Usk River Basin will be extracted through processing Landsat 8 and soil data satellite images.

4 Results and discussion

4.1 The digital elevation model (DEM) and Landsat 8 of the AOI

The morphological (engineering) elements of the surface of the drainage basins are of great importance in influencing the characteristics of the runoff in terms of speed, direction, rate and quantity, which makes establishing these characteristics very important when conducting any of the analyses of the various hydrological features of the basin, as they greatly affect the water runoff inside the basin. Through the DEM of the Usk River Basin shown in Figure 2, it is noticed that the basin surface levels reach 879 m at the extreme northern and southern borders located in the middle of the basin, then the levels are lower than that on all the constituent borders of the basin (Northern, Southern, Eastern, and Western). In respect of the lands located at the top of the Usk River Basin (at the source), they are of medium elevations, as the lands that make up the basin begin with a sharp decline starting from the middle of the basin at the Abergavenny area, then a harsh descent begins as the river approaches the mouth, as the lands located at the basin the Lower Usk River, its levels are very shallow and equal to (–32) m or less than that,

until all the valleys that make up the Usk River end at the main mouth at the city of Newport. The elevated areas whose levels are greater than (0) m are vast and include most of the areas of the Usk River Basin by approximately (80%), except for a small part of the lands whose levels are less than (0) m, which constitutes (20%) as they are those areas located in the upper part of the Usk River near the mouth. Figure 3 shows the extracted Landsat 8 of the area of interest (AOI) as it is showing the Near Infrared (NIR) (Red) (band 5), Green (Band 4) and Blue (Band 3) Sensors.

Figure 2 The digital elevation model (DEM) of the AOI (see online version for colours)

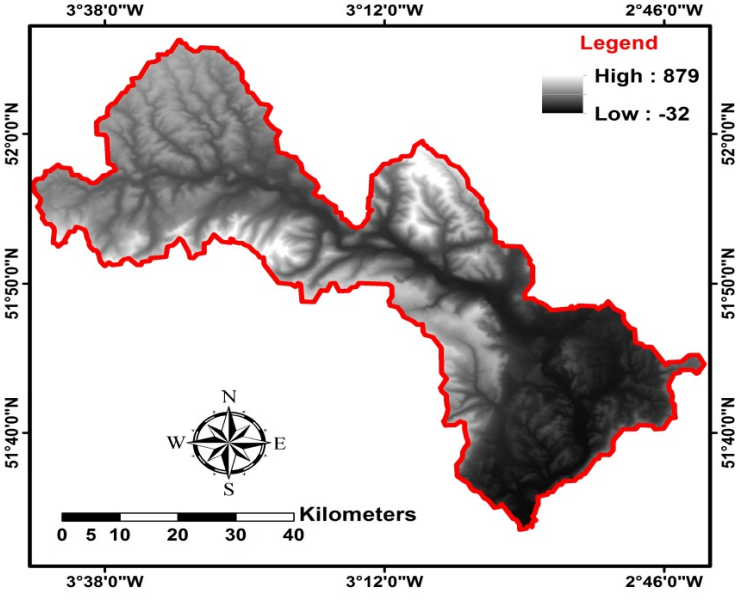
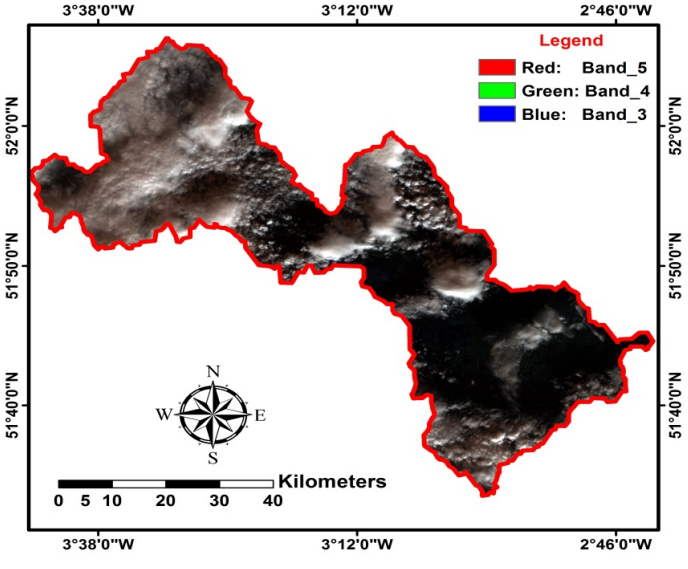


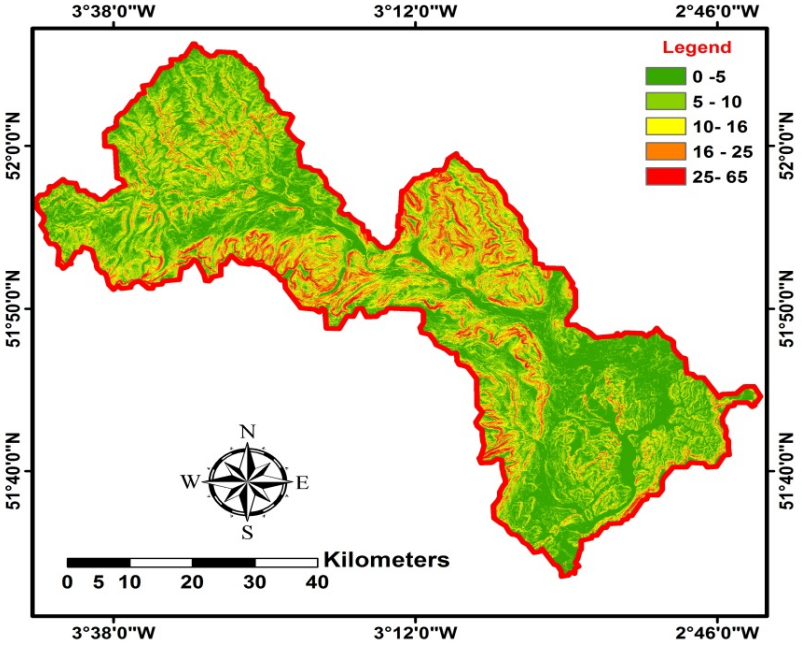
Figure 3 Landsat 8 of the AOI (see online version for colours)



4.2 Slope map of the AOI

The slope of the surface largely controls the surface water runoff velocity, with a great control over the flow direction and valley streams, which largely determines the flow velocity and the time for the water to reach the mouth of the basin. Slope affects the hydrological characteristics of the basin through its two main elements: the degree of slope and its direction within the basin. The maximum slope of the Usk River Basin is 65 degrees in the northern and southern elevations located in the middle of the river basin, in addition to some scattered elevations spread across the river bed. The categories of regression degrees were distributed into five categories. The slope degree category (0–5) degrees is distributed almost completely on the upper part at the source of the river and the lower part that approaches the estuary, and this pattern is followed by the distribution of the category (5–10) degrees, located adjacently in most of the areas at the bottom and top of the Usk River. Slope category (10–16) degrees is densely distributed in the middle of the river basin, and its spread is less dense at the source of the river located in the north of the basin, while it is very limited at the mouth. Categories (16–25) degrees and (25–65) degrees are mostly contiguous and located on the borders of the Usk River and the borders of its branches, meaning that they determine the direction of flow at the confluence of the ranks of the branching valleys of the second and third degrees. In general it is evident that the slope of the basin of the Usk River is from the upper part at the city of Brecon towards the lower part at the mouth at the city of Newport as shown in Figure 4.

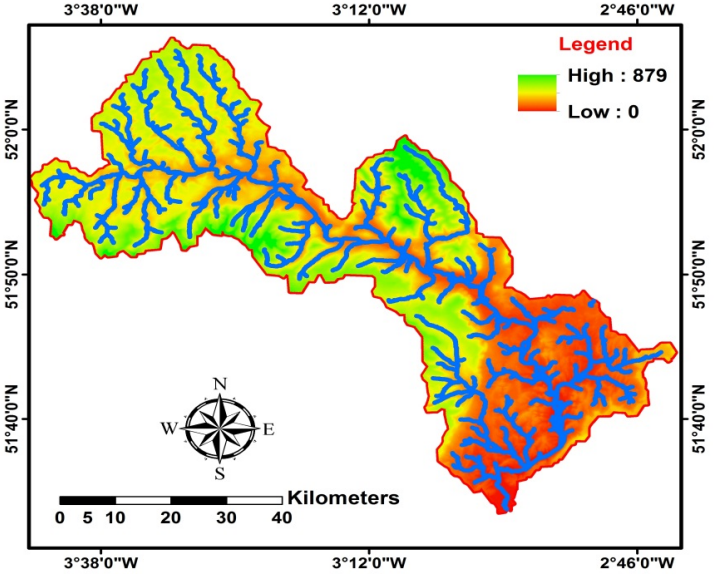
Figure 4 Slope map of the AOI (see online version for colours)



4.3 Drainage map of the AOI

The elements of the drainage network and their morphometric characteristics affect the density of water runoff, its degree of gravity, and the amount of load expected to be carried by the water. It also represents an important element in estimating the amount of water discharge to the river basin. The characteristics of the network include the rank and number of sewers, their branching rate, total lengths, discharge density, and the frequency of sewage within the basin. Figure 5 shows a map of the streams that branch out from the Usk River, forming a drainage network that feeds the lands of the basin with water. As the main branch starts from the upper of the Usk River in the far northwest at the city of (Brecon), in which the watercourse level is approximately 879 m, and it descends downward towards the southeast from the mouth in the city of (Newport) to have the level of the waterways that flow into the Usk River equal to (0 m). It is noticed from the stream network that the branches that flow into the Usk River are many and forked within the river basin and are far away from the main river course, but as a result of the terrain, which is represented by the high elevations of the lands located on both sides of the Usk River, this would have forced the waterways to descend downward towards the Usk River to be the main catchment of water and then down to the mouth at the lower part of the Usk River.

Figure 5 Drainage map of the AOI (see online version for colours)



4.4 Soil map of the AOI

In respect of the soil spread in the basin, it witnesses a diversity in its varieties or types and a difference in its texture, due to the combination of the different geological (clay) structures, the morphology and topography of the basin, and the climatic conditions of the basin lands, as shown in Figure 6. As a result of the aforementioned factors, it led to a difference in the hydrological and physical characteristics of the soil in terms of their

impact on the surface runoff values in the basin, and among these characteristics are the field capacity and the wilting point of the soil, which affect the extent to which the soil retains moisture. That is, the relationship between them is a direct relationship. The soil can be classified based on its tissues spread in the basin into four categories:

1 Loam soil, which constitutes (80%) of the basin lands, and is found in most areas of the river basin with a permeability coefficient equal to (K = 0.2727 m/day)/

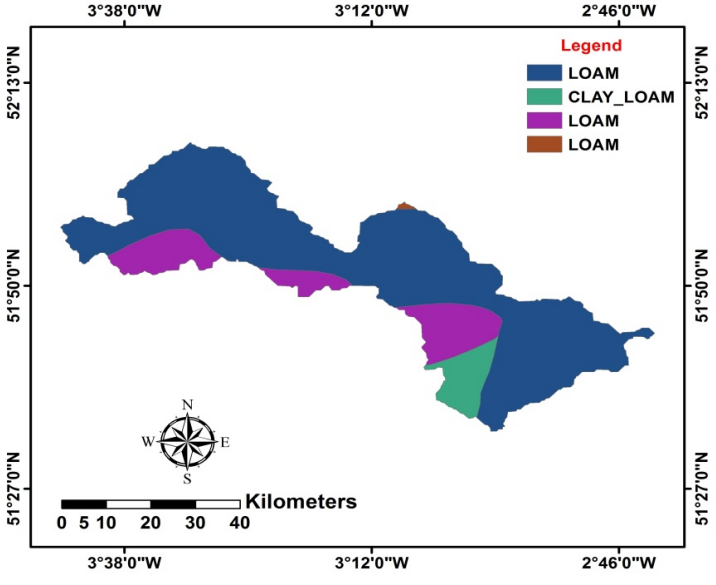
2 Clay-loam soil, which constitutes (4%) of the basin lands, and is located in the southern lower part of the Usk River, where its permeability coefficient is equal to (20.76 m/day).

3 Loam soil, which constitutes (15.5%) of the lands of the Usk River Basin, which is located in the upper southern and lower southern parts and in the middle of the river basin in the south, its permeability coefficient is equal to (58.58 m/day), which is very large compared to the permeability of other soils that make up the river basin.

4 Loam soil, which constitutes (0.5%) and is located in the far north of the middle of the Usk River Basin and has a permeability coefficient equal to (9.64 m/day).

In general, it is noticed that the greater part of the Usk River Basin is a loamy soil, which is characterised by its low permeability and therefore has higher runoff rates than other types of soils.

Figure 6 Soil map of the AOI (see online version for colours)



4.5 Topographic wetness index (TWI) of the AOI

The topographic wetness index (TWI) represents the spatial probability distribution of moisture concentration, and expresses the topographical control over the hydrological processes, depending on the morphometric characteristics of the water drainage network represented by the flow visibility and the topographic slope ratio of the basin surface.

TWI is calculated through a visual relationship (Accumulated Flow) that is derived from the satellite image (DEM) and the topographic slope, which is also extracted from a visual (DEM). Using the tool (Raster Calculator) provided by the GIS program, it is possible to find the TWI image of the Usk River based on the following equation (Beven and Kirkby, 1979):

$$TWI = Ln\left(\frac{A_S}{Tan\beta}\right) \tag{1}$$

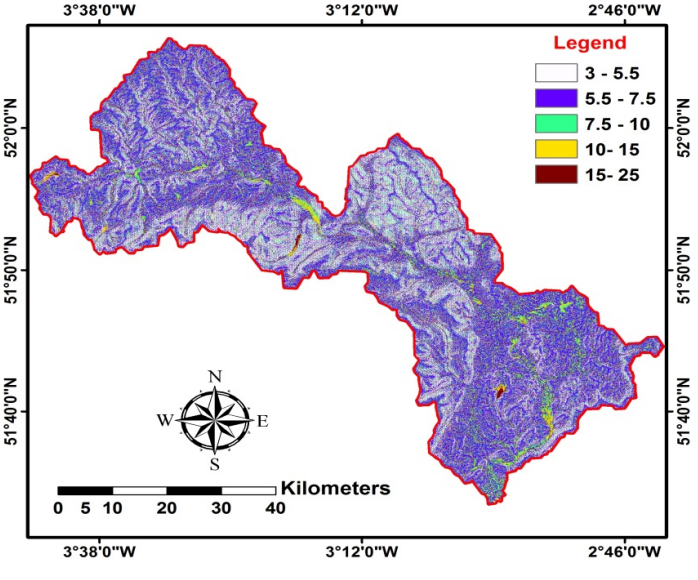
where:

A_S: Cell values in the accumulated flow image calculated in (m^2)

β: The surface slope angle of the drainage basin, in degrees.

The results of the analysis of the Usk River Basin shown in Figure 7 showed that the TWI is generally concentrated in the entire river basin, but in varying proportions. It is noticed from the figure that the moisture values are (3–5.5) with an intensity in the town located north and south of the middle of the Usk River, specifically in the city (Abergavenny), while it is less intense in the areas located at the source (Upper Usk). In most of the river basin, the moisture ranges (5.5–7.5), while it rises in the areas surrounding the Usk River and its branches that descend from it to be between (7.5–10) and (10–15). Sometimes the moisture values are high and range (15–25) in those areas where water collects to form lakes or small watersheds.

Figure 7 Topographic wetness index (TWI) of the AOI (see online version for colours)



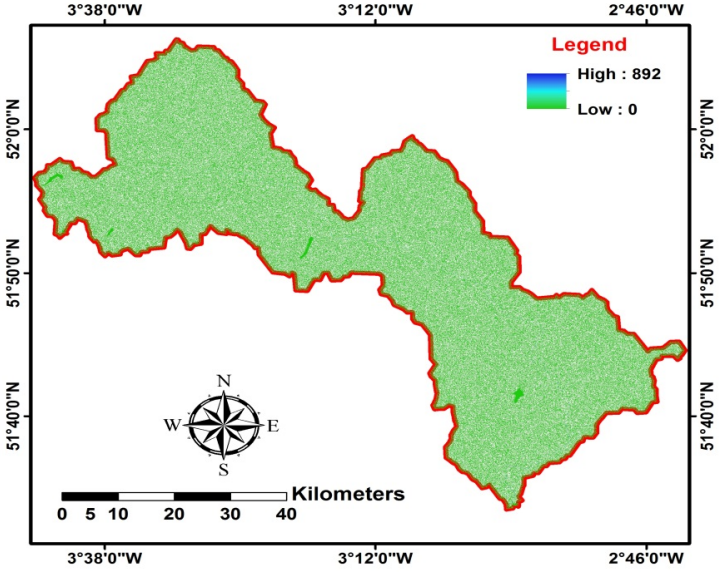
4.6 Sediment transport index (STI) of the AOI

The sediment transport index (STI) is used to evaluate the morphometric factor of the river sediment concentration areas in the drainage network based on the visualisation of the waterways and the slope ratios in the water basin, which are extracted through visual

processing (DEM) of the study area based on the GIS program. The STI is calculated by the following equation (Moore and Bursh, 1986; Al-Zayoud, 2017):

$$STI = \left(\frac{A_S}{22.13}\right)^{0.6} * \left(\frac{Sin\beta}{0.0896}\right)^{1.3} \quad (2)$$

Figure 8 Sediment transport index (STI) of the AOI (see online version for colours)



The results of the analysis for the Usk River Basin shown in Figure 8 showed that the values of the STI ranged (0–892). As most of the riverbeds branching from the Usk River and spread in the river basin in addition to the main course of the Usk River, it is noticed that they do not suffer greatly from the presence of sediment in large quantities in their streams, and the reason for this is due to several factors, including:

1 The flow of water in the Usk River is large and fast, due to the topography of the region, as the river originates from a high area (Upper Usk) in the city of (Brecon) and descends down to areas with low levels at the city of (Newport), where most of the areas surrounding the river and its branches are areas of high levels.

2 The stability of the flow of river water reduces the amount of sediment transferred during its flow.

3 The effort carried by the running water through the river and its branches, where the less the effort, the less the carving process of the bottom or sides of the river, and thus the quantities of sediment transferred decrease.

4 The shape and size of the sediment, where the larger the size of the sediment, the higher the river water velocities needed in order for the carrying and transportation process to take place, while if the suspended sediment is small, it is easy to carry it from one place to another, and therefore the transferred quantities are few and ineffective.

5 The shape and topography of the river channel and its branches, where the larger and more tortuous the river or the branches that branch from it, the more difficult it is to transport sediments, as a result of the many meanders, as well as the roughness and friction that prevent the process of transporting sediments easily. In addition, the cross-section of the river channel or its branches (length, width, and depth) greatly controls the amounts of water flowing through it, and thus this in turn controls the amounts of sediment that can be carried and transported.

5 Conclusion

Water basins and dry valley systems are among the most targeted geographical environments for morphometric and hydrological studies, due to their economic value in the field of developing the exploitation of water resources. As the hydrological systems are based directly on the morphometric characteristics of the water basins, and the morphometric characteristics constitute a major source for the development of water resources projects, such as rain harvesting, water dam projects, vegetation development projects, and others. Most hydrological studies depend on building a database of morphometric measurements before starting a study of hydrological characteristics or starting to implement projects that depend on it. There are environmental and geological evidences that indicate that morphometric characteristics are directly related to water sources and that the surface drainage network of any basin is usually affected by nature's influences, such as topography and climate.

The current study focuses mainly on the Usk River Basin located in the State of Wales, UK, with the aim of conducting an analytical hydrological study and benefiting from it in knowing the environmental, climatic and topographical factors that could negatively affect the basin. The basin of the Usk River is located within the geographical boundaries longitude (51°32′31″)N and latitudes (2°59′6″)W.

The DEM satellite image and the Landsat 8 image of the study area are downloaded in order to benefit from its analysis using the GIS program and to obtain the hydrological parameters. Through the analysis of the DEM image, it has been noted that the river basin has high terrain levels at the source in the city of Brecon, where the height of the land in this region reaches approximately 879 m, while the levels of the ground at the mouth of the city of Newport are (–32 m), which allows the water running in the course of the main river and the sub-streams branching from it to smoothly move down from the source to the estuary. Most of the areas located on the sides of the main course of the Usk River and its subsidiary streams are surrounded by mountain ranges or somewhat high elevations, as well as fertile agricultural lands. The slope of the river basin, in addition to the secondary streams that branch out from the Usk River, appear to descend down from the northwest of the basin to the southeast of it to flow into the city of Newport. In general, the fertile (loam) soil is spread over most areas of the river basin, and it is a soil with good agricultural potential and does not contain gypsum or alluvial materials that reduce the efficiency of the basin for water or agricultural uses. The results of the hydrological analysis of the TWI shows that the Usk River Basin has moisture spread through it, but in varying proportions. In most of the river basin, the TWI ranges between (5.5–7.5), while it rises in the areas surrounding the Usk River or the branches that descend from it to be between (7.5–10) and (10–15). Sometimes the TWI values are high

and range from (15–25) in those areas where the water collects to form lakes or small watersheds. With regard to the sediment transfer index (STI), it has observed through the hydrological analysis process that the Usk River and its branches do not suffer from the quantities of sediment transported by the running water, as a result of the steep slope of the river bed and its branches and the lands forming the river basin, this limits the transfer of sediment and does not affect the efficiency of the river and its branches. It has been observed that the values of the sediment transport coefficient ranged (0–892), and this indicates that most of the river streams branching from the Usk River and spread in the river basin, in addition to the main stream of the Usk River, do not suffer greatly from the presence of sediment in large quantities.

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