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Corresponding Author: *marm16023@marine.aegean.gr

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Time-lapse graphical representation methods for mapping of Intermittent Rivers and Ephemeral Streams (IRES)

Maria-Danae **STAMATAKI**[1*],
Ourania **TZORAKI**[1],
Eric **SAUQUET**[2]

[1] *University of the Aegean, Greece*
[2] *National Research Institute of Science and Technology for Environment and Agriculture (IRSTEA), France*

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Abstract

Flow data visualizations describe runoff, flooding or drought, showing the interconnectivity and complexity of water data issues or water management problems. Intermittent Flow Rivers constitute more than half of the length of the global river network and their presence is expanding in response to climate change. A new approach is developed to visualize the flow of the Intermittent Rivers and Ephemeral Streams (IRES) based on the creation of time-lapse videos. Two statistical methods, the Natural Breaks and Equal Interval one, are used and evaluated for the creation of the mapping content. The flow dataset of IRES for the island of Crete (in Greece) is used as a case study for a six-year period. The results of both methods are used as an input to create the time-lapse videos of IRES. The videos show the flow fluctuation and cessation during a six-year period and the differences between the two methods.

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1. INTRODUCTION

Hydrological extremes such as drought and flood events, as well as hydrological bodies alteration due to human impact or climate change have increased the global scientific interest for the Intermittent Rivers and Ephemeral Streams (IRES) (Beaufort et al. 2018). IRES flowing intermittently over a period of time are the dominant river networks in many arid and semi-arid regions and can be found in various climates (Datry et al., 2017). Especially in water scarce areas, IRES are used intensively for water diversion and storage for irrigation, hydropower production, channelization and urbanization (Tzoraki et al., 2020). Recent studies revealed their unique ecosystems processes to conserve their biodiversity (Datry, Singer, et al. 2017). Spatial patterns of the IRES affect several hydrological processes considering the watershed management (irrigation, water abstraction, river damming, pollution) as well as the monitoring protocol for effective use of resources.

A perennial river flows throughout the year through parts of its stream bed during years of normal rainfall. In contrast, in many intermittent streams, remnant pools persist after flow ceases. During a wetting-drying cycle, IRES pass from the permanent flow phase to a non-flowing pool phase and then a dry phase when surface water disappears (Datry, Bonada, and Boulton 2017). These types of flow in a river can create many water states such us flooding, riffles, connected pools, pools, dry stream and dry alluvium (Gallart et al. 2012). Riffles are usually swift and shallow parts of a river, and pools are typically the deeper reaches of a stream that formed on low flows or have moderate velocities and little surface turbulence. It is important to record the different states of the river. The hydrological patterns of intermittent rivers can be acquired by several technologies such as remote sensing technology (aerial and satellite images), acoustic Doppler current profilers (ADCPs), use of digital photogrammetry processing techniques and UAVs (Koutalakis, Tzoraki, and Zaimes 2019) or the combination of them (Borg Galea et al. 2019) and by field research and data collection by citizens (i.e. crowdwater application) (Etter et al. 2018).

Visualizations about water use are necessary, according to USGS, and the use of them is crucial for interpreting the actual state of water usage, river condition, integrated water availability, or water footprints (Dieter et al. 2015). Also the study floods and floodplains in general should consider historical flow data, when available, as they play an important role in understanding and optimizing natural hazards. More than half of the global river network is composed of intermittent rivers and ephemeral streams (IRES), which are very important for the environmental conservation, the supply of food and for the provision of leisure activities. Of course, Since IRES are unpredictable systems, they need to be studied thoroughly (Datry, Singer, et al. 2017).

IRES mapping of known accuracy depicting large regions of specific flow phases and flow types and specific timelines (high, low and no-flow periods) is inherently impractical. However, novel modelling techniques and visualization methods have been developed in recent studies to provide information about IRES hydrologic regime and alteration due to climate change and human activities. There are many types of maps: administrative, heat, statistical, trajectory, bubble maps, etc. These are examples of mapping content that can be created according to what the point of interest. Maps can be divided into 2D, 3D or static maps, dynamic and interactive maps. They are often used in combination with points, lines, bubbles, and more. The visualization depicts the relationships between the data, with images, allowing patterns or trends to be visible. So, there is a need to be able to interpret increasingly larger batches of data and show the flow phases variations, summarized in a map or other method of visualization.

Most IRES data is strongly dependent on the time of measurement since flow runoff is present only at specific months during the year. In most studies, the time variable is excluded, and flow mapping considers yearly or in some cases seasonally runoff data. Even though the mapping of the average flow can give adequate results, it cannot visualize hydrological changes such as the floods or the cessation. The objective of the current work is to develop a methodology to visualize the IRES flow over time. The innovation of this study is that the parameter of the time is considered in a series of mapping content, in which monthly flow mapping snapshots are joined to create a time-lapse video of the stream. The IRES of the island of Crete is used as a case study. Also, a more comprehensive visualization of river flow is created for people with different scientific backgrounds to understand how intermittent rivers work and what is their flow power.

2. METHODOLOGY

2.1 Study Area

According to the Ministry of Environment and Energy of Greece (see figure 1), the Water District of Crete (with the code EL13), is the southernmost water district of the country and consists of the homonymous large island along with the small islands around it, mainly Gavdos and Zeus. Its area is 8,345 km2. The relief of the island is intense with large mountains. The main mountain series are the White Mountains, Psiloritis, Talea mountains, Asterousia, Dikti and the Lassithi Mountains. Within the large mountains there are important plateaus such as Omalos and Askifos in the White Mountains and the Lassithi Plateau in Dikti. The present climate of Crete is sub-humid Mediterranean with humid and relatively cold winters and dry and warm summers. Its lowland zone is characterized by low rainfall, mild winter and long dry period. Crete is considered a semi-arid region. The annual rainfall ranges from 300 to 700 mm in the low areas and along the coast, and from 700 to 1000 mm in the plains of the mainland, while in the mountainous areas it reaches up to 2000 mm. The major water use in Crete is irrigation for agriculture (84.5% of the total consumption), while domestic use is 12% and other uses 3.5%.

The Water District of Crete consists of three (3) main River Basins those of the Streams of the Northern Section of Chania - Rethymno - Heraklion (EL39), the Streams of the Southern Section of Chania - Rethymno - Heraklion (EL40) and the Streams of Eastern Crete (EL41) (Figure 2). The area of the basins of the northern part of Chania - Rethymno - Heraklion is 3676 km2. This catchment area occupies most of the northern part of the island. It includes areas of the prefectures of Chania, Rethymno, Heraklion and Lassithi. It is bordered along the West-East axis by the ridges of the White Mountains and Psiloritis and includes the Lassithi plateau in its eastern-most part. The area of the Streams of the Southern Section of Chania - Rethymno - Heraklion is 2798 km2. It occupies most of the southern part of the island. It includes areas of the Regional Units of Chania, Rethymno, Heraklion and a small part of the Regional Unit of Lassithi. It is bordered by the ridges of the White Mountains, Psiloritis and Dikti. The west coast of the area to the south is steep with large slopes and gorges. The area of the river basin of Eastern Crete is 1870 km2 and includes the largest percentage of P.E. Lassithi. It is delimited by the ridges of Mountain Dikti. The main rivers of Crete are Geropotamos, Anapodaris, Giofyros Tavronitis, Kalamafkianos, Bramianos, Aposelemis. Geropotamos is the largest river in the Water District of Crete. It has a length of 45.6 km and its catchment area is 592.9 km2.

Figure 1. The water district of Crete (EL 13), Ministry of Environment and Energy of Greece (geodata.gov.gr)

Figure 2. River Basins of Crete (Source: FEK 1572 B /28-9-2010 published in the Official Gazette)

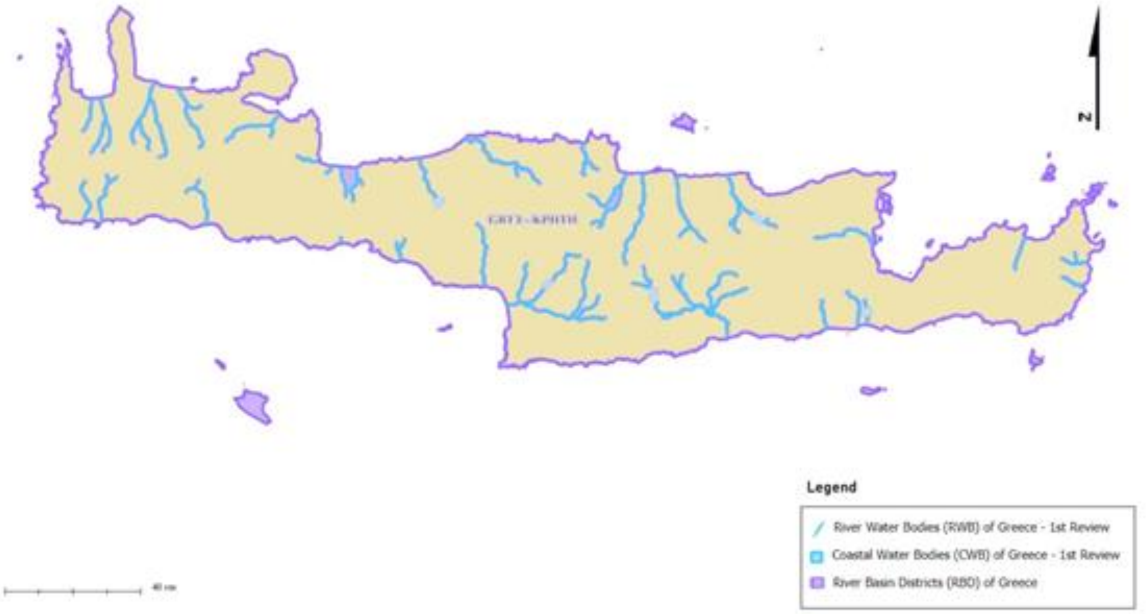

Figure 3. Rivers of Crete

According to the Decentralized Administration of Crete dataset there are 25 recorded intermittent flow rivers, with most of them found in the Heraklion prefecture (Table 1).

Table 1. Intermittent Rivers of Crete

Region	Intermittent river	Flow Data Availability
Lasithi	Kalamafkianos	Yes
	Bramianos	No
	Mirtos	Yes
	Oropedio Lasithiou	No
	Patelis	No
Rethimnon	Agios Vasilios	No
	Platis	Yes
	Prassanos	Yes
	Geropotamos Rethimnou	Yes
	Kourtaliwtis	Yes

Heraklion	Almiros Anapodaris(Demati) Anapodaris(Plakiotissa) Aposelemis Arvi Gazanos Giofyros Iniotis Koutsoulidis Lithaios Baritis	Yes Yes Yes No No Yes Yes No No Yes No
Chania	Kakodikianos Kakopetro Mesavlia Roumatianos Sepreniotis Tavronitis	Yes No No No No Yes

Source: Author's elaboration

2.2 Material and Methods

The method developed in this study to visualize the intermittent flow streams is shortly presented in the research methodology tree (Figure 4). The processing of primary data (flow time series and spatial GIS data) is the first step of the methodology. The flow data of the available gauging stations of Crete were extracted from IRES dataset and the spatial data were obtained (Shapefile of station points-river lines-land borders, DEM) from the open EU datasets, such as Copernicus Land Monitoring Service, Geodata.gov.gr and Hydroscope.

The spatial data concerning flow measurements were digitized, and Open Source data (river shapefiles, DEM, County Boundaries, Station Points) were obtained. At this point, the map data were corrected to allow proper overlapping of the layers. The use of Digital Terrain Model (DEM) gives the three-dimensional substance of space on a map. It consists of a plurality of altimeters in normal or non-layered form, as well as discontinuity lines and brake lines which attribute the geomorphological characteristics and soil abnormalities such as road boundaries, building contours, water boundaries, embankments or steep falls. The DEM that was used in this study was from Copernicus Land monitoring service, the EU-DEM v 1.1. After creating a raster file in ArcMap, the elevation of the basins was added to the data layers, providing us with information about the altitude on each line that represented the studied rivers. The DEM is used as the background base map, since the cartographic background was created, to unify the spreadsheets with the flow data.

The database of IRES discharge flow time series streams of 15 European countries have been created in the framework of the SMIRES COST action (Datry, Singer, et al. 2017). The selected rivers are characterized by natural or moderately altered hydrologic regime, with catchment area smaller than 2000km². Due to space restriction, the IRES dataset of Crete Island is selected as a case study. It includes 31 flow stations (See Appendix) in 14 river basins, which after corrections and processing are used for the current analysis. Only the gauging stations of complete flow time series are considered. However, the gauging stations provides flow data at specific transects and do not cover the entire area of the river. That means, the flow condition is not known for parts of the river that are much further from the station, i.e., near its estuary or its sources. It is hypothesized that the gauging stations data are representative for the whole stream. All flows units have been homogenized and converted to l/s. For 14 stations are available complete time series of monthly instant flows from September 1990 to August 1996 (Figure 5). The results were summarized in tabular form and the units of measurement were converted to l/s, where needed.

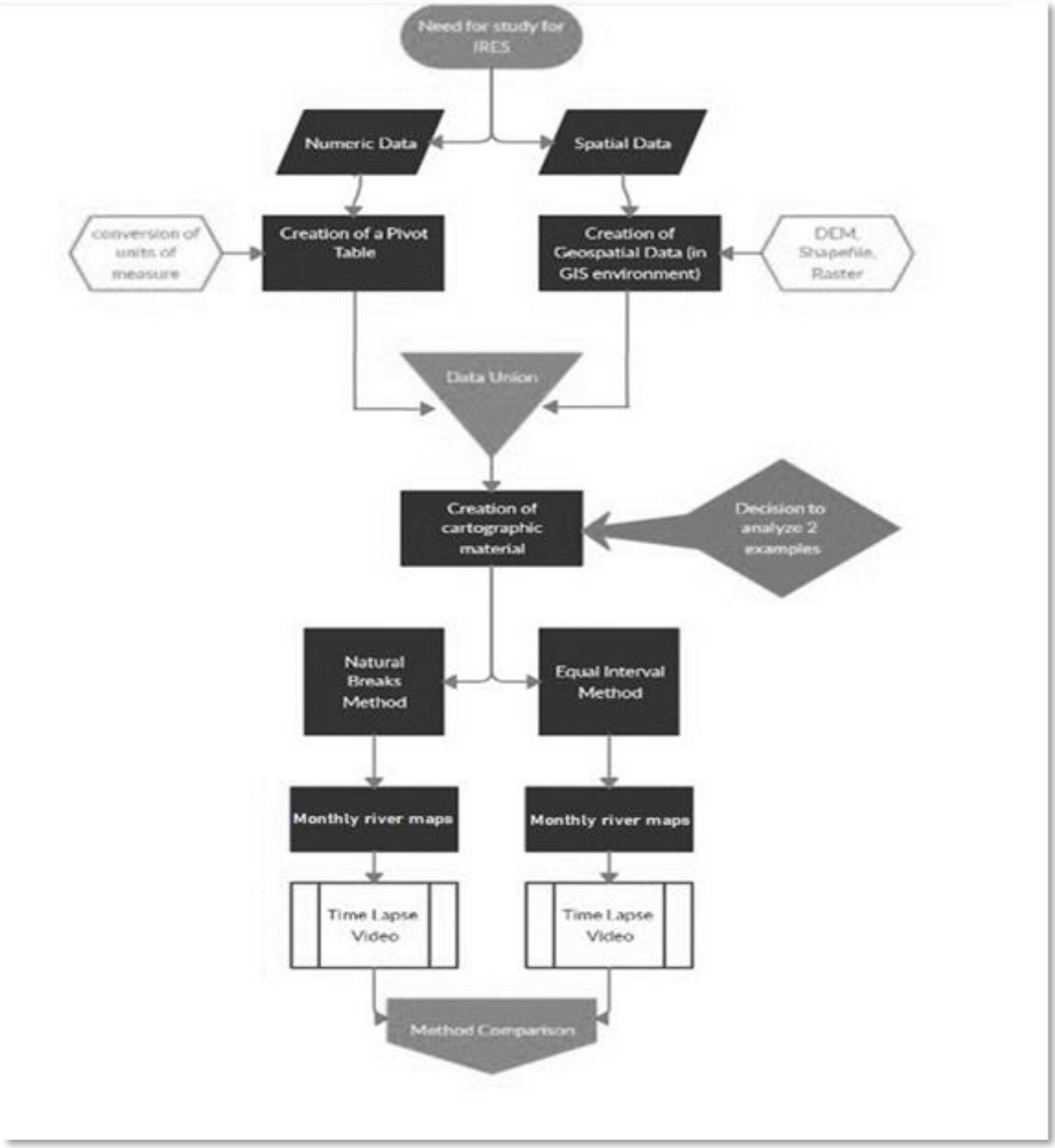

Figure 4. Methodology tree of the case study

Then, all the flow data was tabulated and linked to ArcGIS to create flow maps. The final dataset includes the geospatial data for the rivers combined with their monthly flows. For each month, responding to a column in the Attribute Table, a map was created. At this point it was necessary to decide which clustering method is the optimal, so that the visual material to be produced is closer to the physical and is comparable. Two methods were studied, the Natural Limit Method and the Equal Intervals method (Osaragi 2014) (Goodchild, Barbara, and Haining 1992). This was required since each method had advantages and disadvantages in terms of the visual result that they exported. These methods are mainly used in statistics, but they also find application in the spatial data clustering (Spatial Statistics)(Goodchild et al. 1992). In the Natural Breaks method, the user selects the number of groups and sets the boundaries to divide the values where there is a large discrepancy. In the Equal Interval method, the difference between the intervals of the grouping scale is equal in its entire length, making the comparison between months feasible.

The four factors that seem to influence the visualization of IRES are:

1. The Time interval
2. The Spatial Resolution
3. Flow Data
4. Cluster Analysis

The time scales commonly used to record available water resources are annual, monthly, daily or hourly. The annual scale is used to construct the annual water mass balance and is important for planning the management of available water in an area but, in contrast, is not adequate for ecological studies. The monthly scale can show the fluctuation of water resources availability during the seasons as the first rains start mainly in October (Autumn), escalate in December and January (Winter) and decrease in summer months. Daily or hourly flow data are mostly used to predict natural hazards such as floods and water scarcity in arid areas.

Inserting the time interval means that we have a map for every different month that was included in the set of data used in the study. This factor has a great influence in the final product. During the 72 months of monthly data, the maximum and the minimum flow measurements had a significant role on the classification of data. The lower flow value is zero (0) l/s, while the upper value depends on what was the maximum value of l/s during only those 72 months. If a period different to 72 months was used in the dataset, the upper value might be different. Since we examine intermittent flow streams, the minimum flow is always zero. Consequently, the selected time interval affects the categorization. The maximum runoff values define the limits of each categorization. Adding more years of flow data, creates a possible new maximum limit on the whole set of data, because each year the maximum flow that is recorded on the station is different, depending strongly on climate extremes. As a result, the produced optical material changes.

Moreover, deciding the spatial resolution of a study is of great importance. If the scale is large, that means that the area that is considered into the study is bigger, and so is the information that can include. If the scale is small, that means that the area that is considered into the study has smaller extent. In this case study a larger area means that more rivers can be visualized, and a smaller area means that at least one river can be observed. For example, the Danube river which is a 2857 km river with a river basin that covers a total area of 801,463 km^2, is shown in maps with 1:4.500.000 scale, which is considered a large scale. Geropotamos river which is approximately 10 km with a river basin of 602 km^2 in Crete is usually depicted in 1:200.000 scale which is small scale.

One important constraint was the processing of the time series of flow data, which some were incomplete or included bias values. Also deciding the cluster analysis method is quite important. After the export of mapping content for both cluster analysis methods (Equal Interval, Natural Breaks), a difference was observed between them. Each data is symbolized by a specific way on the map, giving a clear message to the observer whether the river had low flow or not.

3. RESULTS

3.1 Flow data

From those two methods 144 maps were exported, 72 for each method. In the maps created with the Natural Breaks method, no legend was posted in each monthly map, as the flow measurements changed in each month and there was not a stable range of flow values. Unlike the Equal Interval method, where there was a specific categorization of flow values during the six-year period. This has made it necessary to visualize all the maps. For this purpose, two videos were produced, in which the presentation of the two methods took place over the time period from September 1990 to August 1996. The software used was Vegas Pro, which enables video editing and, more generally, visual material. Each frame of fifteen (15) seconds was a map concerning a time period of a month. At the end of the process, the methods were compared and evaluated.

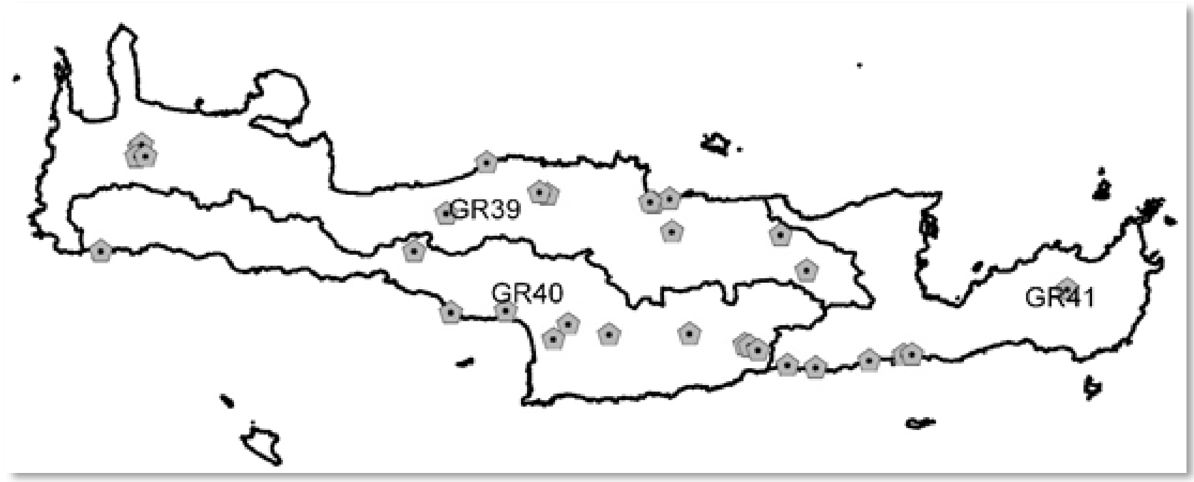

Figure 5. Stations for flow measurements in Crete

These six hydrological years (1990-1996) were chosen because they were the most recent and the data set for all the rivers were complete (Table 2). Two methods have been applied, the Natural Breaks method and the Equal Interval method, considering the methods advantages and disadvantages in terms of the visual effect they exported. These methods are mainly used in statistics, but they also apply to spatial clustering (Zacharopoulou C., 2011). Thus, it was necessary to visualize all the 72 map products for each method.

To this end, two videos were produced, in which the two methods were presented, over the period from September 1990 to August 1996. Creating a time lapse video helped in the comparison of the two methods, pointing the advantages and disadvantages of each method concerning the visualization outcome.

When the Equal Interval method is applied, the difference between the intervals of the grouping scale is equal in its entire length, making the comparison between months feasible (See Fig. 6). In the case of the six hydrological years the limits set for each river were dependent on the maximum flow rate and the minimum flow rate relative to all rivers. Each range was given a different line width to show the flow difference in each river. Subsequently, a total of seventy-two (72) maps were created for all months from 1990 to 1996. In general, using this method makes it possible to make more use of ordinal scale data than on other scales, which gives us much more information. The ordinal scale allows for rank order by which data can be sorted. Still, it does not allow for relative degree of difference between the methods. Of course, this method is observed to be affected by the maximum and minimum measurement of the data set and the result is shown in the video created for this purpose. The maximum and the minimum were decided after finding the maximum and the minimum of the flow measurements between those six (6) hydrological years.

Table 2. Monthly Data used in the study from 1990 to 1996

Month / Year	1990	1991	1992	1993	1994	1995	1996
September	✓	✓	✓	✓	✓	✓	✗
October	✓	✓	✓	✓	✓	✓	✗
November	✓	✓	✓	✓	✓	✓	✗
December	✓	✓	✓	✓	✓	✓	✗
January	✗	✓	✓	✓	✓	✓	✓
February	✗	✓	✓	✓	✓	✓	✓
March	✗	✓	✓	✓	✓	✓	✓
April	✗	✓	✓	✓	✓	✓	✓
May	✗	✓	✓	✓	✓	✓	✓
June	✗	✓	✓	✓	✓	✓	✓
July	✗	✓	✓	✓	✓	✓	✓
August	✗	✓	✓	✓	✓	✓	✓

Source: Author's elaboration

When the Natural Breaks method is applied, the user selects the number of groups and sets the boundaries to divide the values where there is a large discrepancy (see fig. 6). In general, the theory behind Natural breaks is that this method is essentially a sorting algorithm that minimizes the deviation from the mean of each class and maximizes the deviation from the mean of the other classes. In most commercial and open-source GIS software this method is one of the algorithms to classify a variable into groups/ classes. Five categories were defined, except that for each month the values of the natural boundary categories were influenced by the minimum and maximum flow values in that month. However, the visual effect is closer to the river image and considers the maximum and minimum of each month rather than the total flow data. This clustering method creates a visual that can help the viewer understand whether the flow is bigger or lower

in the river of the area. Seventy-two (72) maps were then created for the months from 1990 to 1996.

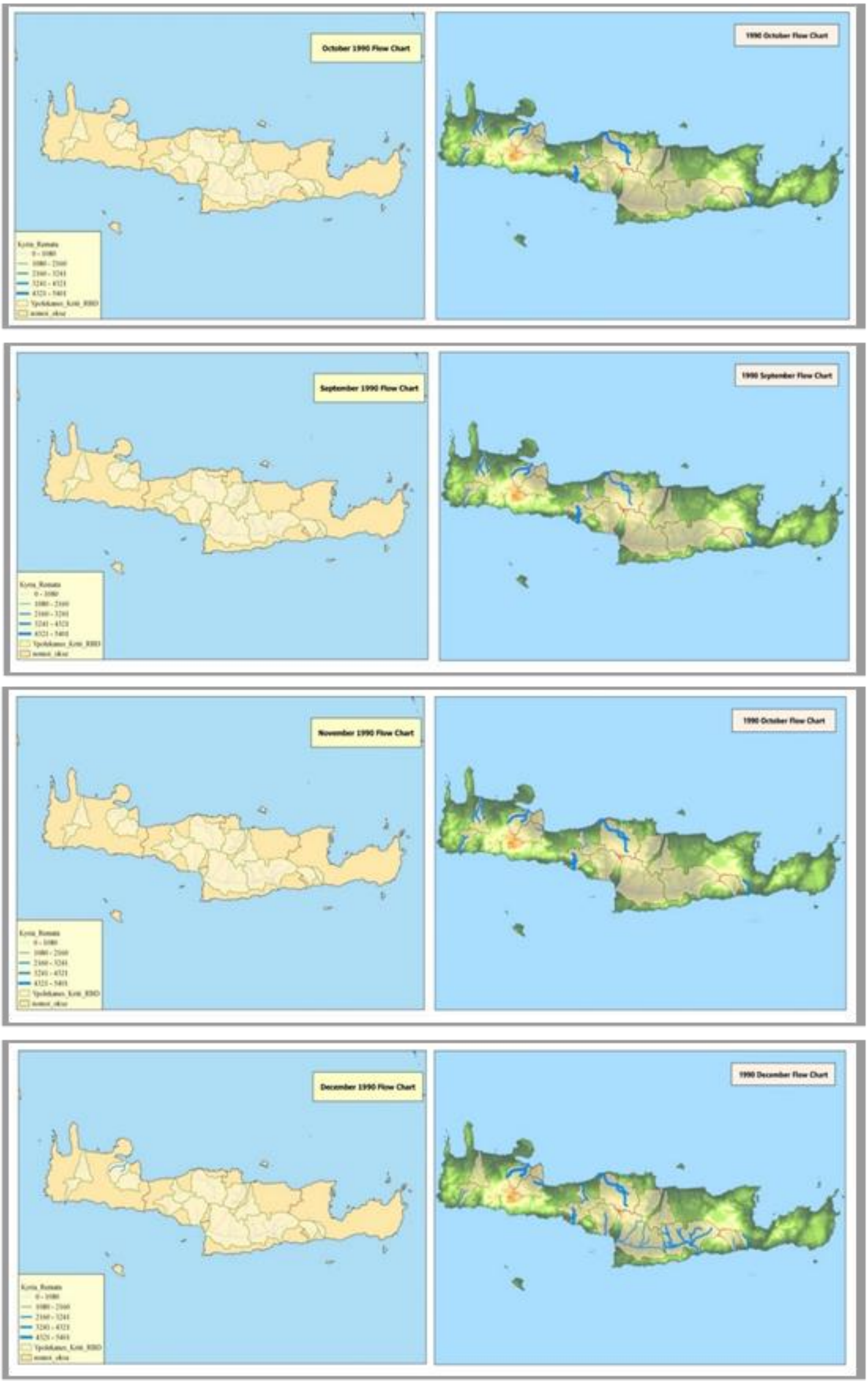

Figure 6. Maps of Natural Breaks (Right) and Equal Interval (Left) from September 1990 to October 1990.

3.2 Time lapse Videos and diffractions of each method

When the Equal Interval method is applied, it was observed that there were no major changes in the flow by river. The boundaries did not change easily for each month, which means that the categories of flows created were not 'sensitive' to fluctuations in flow values. The categorization was consistent for all rivers and thus comparable. This is because comparisons can be made between two-month streams, for example, since the categories remain the same. In a nutshell, the river flow situation is comparable when two or more maps with the same clustering scale in the legend exist. Concerning the disadvantages of this method, it has been observed that the maximum value of the river flows is those that affect the method ranges. If time decreases or increases, then these ranges would change again. For example, in the six years of this study, the maximum value was 5401.1 l/s. But if the study time is reduced, then the maximum flow will change. Consequently, the classes of categorization will change from the beginning. The second disadvantage is that small differences in water flow is not depicted on the map, due to the specific flow categories, because most of the rivers, during all seasons and years reach the same flow category. As a result, no fluctuation in the flow intermittence of rivers can be observed.

When the Natural Breaks method is applied, river flow variations have been observed, as these calculate values that are highly divergent from one another. The method is sensitive to the flow values. Monthly data are the ones that influence the natural value limits. That is, the visual material gives the opportunity for a more natural visual approach to flow on the map. In this method the visual result is not affected by all year data but only by the monthly measurements.

The results obtained do not exclude either of the two categorization methods. What needs to be understood is that data aggregation is a decision that must be made depending on the subject of the study. In addition, it should be noted that the flow data entered was a result of a station usually measured in the central part of the river. This resulted in one month's flow being assumed to be the same across the river. Something which is not true but for the approximate study all parts of the river had the same flow.

4. DISCUSSION

Following the general workflow of the methodology used for this case study can be generalized to more statistical and clustering methods of spatially distributed data of river flow. In this case the time series were chosen by their availability. SMIRES dataset given in order this study to be done, was crucial. Some of the time series were not entirely completed so the selection of rivers was done according to which time period more river data was available and in the majority of basins operate only one gauging station. Among many case studies, concerning Intermittent River flow visualization and flow measurement techniques, it is commonly shown than the main problem is the way that flow can be measured without using ground gauges (Tauro et al. 2014, 2016). Also, intermittent rivers usually are difficult to reach for ground gauges to be installed. Many rivers on the planet are inaccessible or have incorrect measurements or data that are not readily available. Furthermore, the calibration of the flow is very crucial to any study for the application of hydrological models (Revilla-Romero et al. 2015). Estimation of water resources using a variety of groundwater models is common. But the accuracy of the models is still largely dependent on the reliability of the input parameters that each study uses (Ragab et al. 2010). The two statistical methods presented here produced different results while they had the same data base. It depends on each study to choose one of them according to the study needs.

In most case studies, one river basin is commonly studied but it is difficult to show data for intermittent rivers in medium scales, in this case, for the island of Crete that requires a relative medium mapping scale. In Geography the term 'scale' is used differently than many other sciences. A large-scale map is where the RF (Representative Fraction) is relatively large. A 1:1200 map is therefore larger scale than a 1:1,000,000 map. The 1:1,000,000 map would usually be called a small-scale map. This is true even though the 1:1,000,000 map would show a much larger area than the 1:1200 map.

That was the main reason that Crete was the study area that this study chose to do this research. The smaller the scale the less the resolution of area data, but the larger the scale the less the general perception of a regional unit. Also, most of the studies relate to data from gauging stations and satellite imagery. The rivers are depicted as lines and when a flow classification must be done, most researchers use color changes or different types of lining styles (dashed line, dots, double line etc.). Giving the river line width can create the illusion to the observer the perception of the scale that the river experience water flow. Crete has sufficient intermittent rivers throughout the regional area. The fourteen rivers of this region created two time-lapse videos that can be useful in order to observe the monthly changes on each one of them and with two different statistical methods. Creating a map for every given point of time, with an alternating order, will create the same results and a time lapse video. Until now, this way of observing things is used by civil protection agencies for flood risk prevention and mitigation, by having life risk zone mapping (Klemas 2015; Pradhan 2009).

Existing data, models and techniques applied to the hydrological study of intermittent Rivers focus on changes in time or space, capturing high or medium resolution dynamics in one of these dimensions, but rarely both or lower resolution (Sefton et al. 2019). In other studies, the export of data is crucial in receiving data from the rivers based on algorithms and Digital Elevation Models. Wu et al. (2011) developed a hierarchical dominant river tracing algorithm to automate the extraction and spatial upgrading of river network rivers in fine scale inputs using zero or nearly one-dimensional information for spatial updating, determining increased flow directions in fine scales (Wu et al. 2011). Various remote sensing techniques have been used to measure proxies for river discharge in order to estimate flow regimes. These techniques include air and space measurements with radar altimeters, wetted areas and bank heights measurements. But all those remotely sensed data are unsuitable for small channels because of resolution issues and the density of vegetation coverage, limiting the use and the application of satellite imagery for mapping many IRES (Wang et al. 2009)(Sichangi, Wang, and Hu 2018). Moreover, it is commonly known that the most river networks that are gauged concern those parts that considered perennial rivers with stations sparsely distributed and they are close to urban areas or places of economic interest. As a result, the rest of the river networks are underrepresented or even degraded. Underestimation of IRES can lead to serious management problems or even cause a natural disaster (floods) (Datry, Bonada, et al. 2017). Such an example is the hazardous floods of 2017 in the town of Mandra, Greece, in which underestimation of an intermittent river in combination with human interventions within the streams, caused major floods within the town (Kastridis and Stathis 2020) .

5. CONCLUSIONS

Being able to visualise and analyse water resource complexities over a period of time is an essential step to understand hydrological patterns (Williams, Lansey and Washbourne 2009. The time factor is significant in visualising flow intermittence. Making available time-lapse graphical representation for a river will facilitate the improvement of the management of the area. Creating visual representation of intermittent rivers is of crucial importance in order to protect areas with high flooding rate. Gathering visual data is also of great importance as in most cases of flood disasters, there were only a small amount of information and data about the area of interest. The present study shows that the Natural Breaks or Equal Interval method could help in the better protection of areas that have not yet been affected by a flooding event and can create a management plan based on visual time-series of flow data. A study like this one can change the understanding of intermittent rivers and of their riparian areas. Data existence is the core of each study. Having complete datasets, time series, good quality imagery and historical records is the best combination of tools to create quality imaging tools. The rivers are inextricably linked to their riparian zones as their terrestrial action greatly affects the riverbed morphology and the river itself. The availability of time-lapse graphical representation of intermittent river flows allows cost-effective and efficient implementation of public works, stream buffer rules, stream mitigation, basin-wide planning, storm-water rules, flood risk protection and management and other similar surface water protection programmes.

APPENDIX

TIME – LAPSE VIDEOS:

- https://youtu.be/4uSdaHEOqOY
- https://youtu.be/jW_IYfCCYxM

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