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CONFLUENCE SATELLITE IMAGE CLASSIFICATION

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Abstract. A confluence is defined as a meeting point where two or more rivers merge to become the source for a new river. This river merge adjusts its geometric parameters depending of the characteristics of its confluent rivers, particularly wide and intersection angle. Based on this idea and supported by the availability of satellite images, in this paper we classificated 43 confluences located in Tabasco, Mexico. We considered the geometry (plan view) and the intersection angle as a key elements, and applied multivariate statistical analysys to did the clasification. Results shown three groups: I. Similarity between the width of the three rivers and intersection angle less than 80°; II. Similarity between the width of the three rivers and intersection angle between 80° and 160°; and III. Similarity between the width of the main river (the largest confluence river) and the river merge, intersection angle less than 100°. Once this classification was done, next step is to do both hydraulic and sedimentological studies, to understand the integral behavior of the confluences and verify that the proposed classification, not only have geometrical similarities, but its hydraulic and sedimentological operation are also similar. Due to difficulty to study many confluences, the best way is to chosee the representative and analyze it. Here we proposed an alternative to do it, that can be useful for scientist, enginnerings and students interested in to study confluences.

Key words: rivers geometry, multivariate statistical analysis, rivers juntion

INTRODUCTION

A confluence is defined as a meeting point of two or more rivers, thus combining the physical-chemical properties of water bodies at the intersection point [Charlton 2008]. The river formed downstream is usually narrower than the sum up of the width of the two rivers upstream. This resultant narrowness after the confluence of the new channel is

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offset by a deeper river bed. That means the new river adjusts its geometrical parameters based on the confluent rivers [Farias 2011]. There are different confluence geometries characterized by their geomorphological, hydraulic and sedimentological variables. For their classification exist different parameters such as: flow rate and river bottom form [Rhoads and Sukhodolov 2001], turbulence [De Serres et al. 1999], composition materials and their scrouting [Ashmore 1983], intersection angle and displacement of meanders [Best 1987], confluent general form [Xiao-gand et al. 2007] and its location in river networks [Benda et al. 2004]. Additionally, laboratory research models have helped to reach conclusions on the behavior pattern of confluences [Ashmore 1983, McLelland et al. 1999, Rhoads et al. 2009]; however, the majority of authors say that more studies are needed to better understand their functioning [Lambs 2004]. In an overall perspective, most of the authors that have studied river confluences agree on the relevance of geometry for their development [Rhoads and Sukhodolov 2001, Parsons et al. 2007, Rice et al. 2008, Zhong-Chao and Ze-Yi 2011, Rooniyan 2014]. Based on these studies and supported on the availability of satellite images, the objective set for this work was to develop a confluence classification depending on the plan view of their geometrical forms, where intersection angles and their widths are considered key elements. This classification is useful because it allows finding geometrical similarities among confluences.

STUDY SITE

In Mexico, rivers and streams form a hydrographic network with almost 633 thousand kilometers length (CONAGUA, 2013), and the main river basins therein are the Bravo, Balsas, and Grijalva-Usumacinta. The latter is located in Tabasco, Mexico (Fig. 1), and transforms it in one of the broadest hydrographic fluvial systems. That is why we chose this region to studied 43 confluences (Fig. 2).

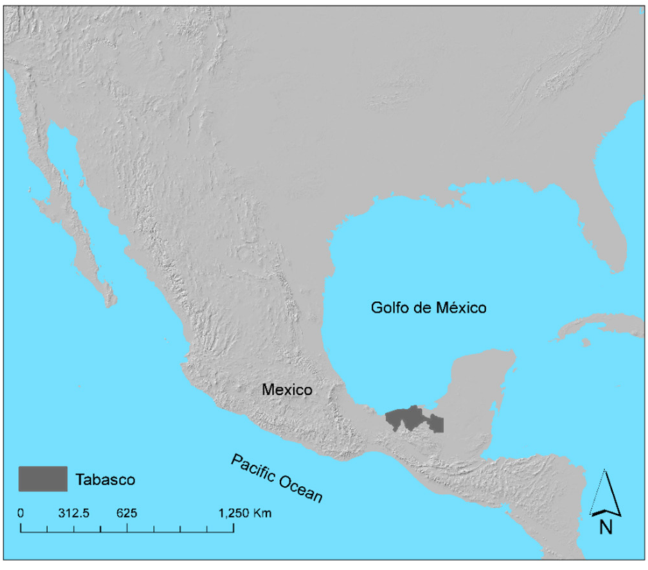


Fig. 1. Tabasco, Mexico

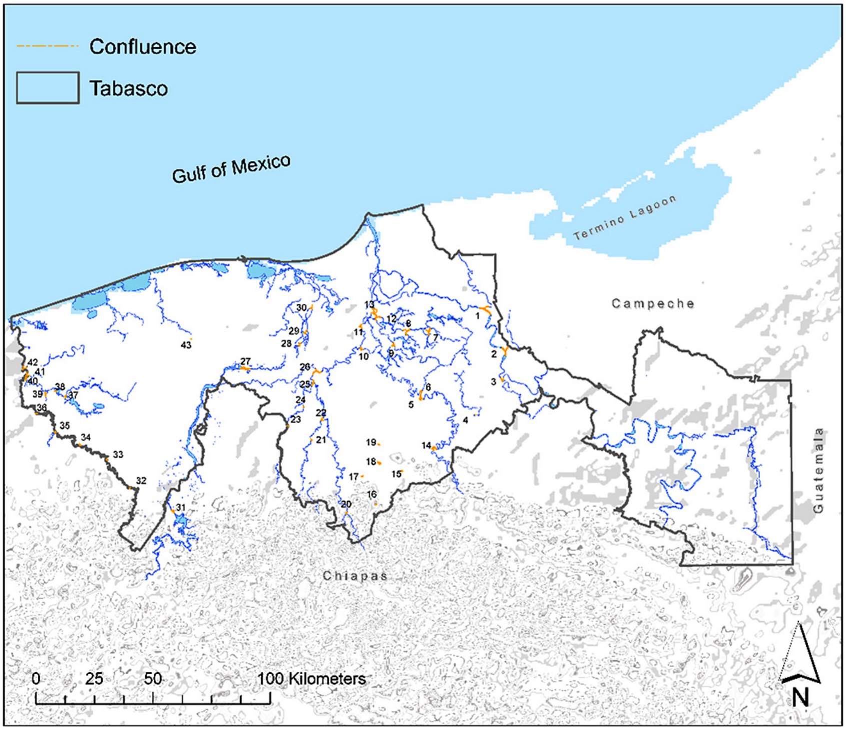


Fig. 2. Study site and 43 confluences analyzed

The Tabasco State is very flat region, with medium slope of 0.0003, high sinuosity and sand rivers. Confluences Examples are: Carrizal-Grijalva (Fig. 3) and Mezcalapa-La Sierra (Fig. 4).

Fig. 3. Carrizal – Grijalva Confluence

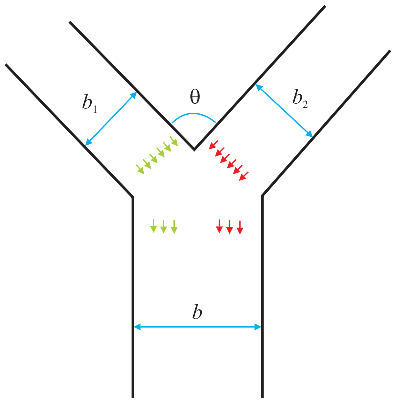
Fig. 4. Mezcalapa – La Sierra Confluence

MATERIALS AND METHODS

We conducted a multivariate statistical analysis to assess the geometrical variables generated from the confluences selected, and we ended up with a classification of three groups: I. Width similarity among the three rivers and an intersection angle of less than 80°; II. Width similarity among the three rivers and an intersection angle ranging from 80° to 160; and III. Width similarity among the main river (larger river), the outflowing river and a small confluent tributary, their intersection angle being less than 100°.

Image Digitalization and Processing

We classified the confluence geometry according to Rhoads et al. (2009), who proposed a classification of confluences depending on the plan view of their geometry (Figure 5).



b_1 – width of the smallest confluent tributary, b_2 – width of the largest confluent river, b – width of the confluence discharge, θ – intersection angle.

Fig. 5. Plan view confluence geometry

Satellite images were got from Google Earth (2016) web site and processed in ArcGis. They provided georeferential information including: elevation, positions and unequal levels. These elements were crucial to identify and locate possible confluences in the selected hydrographic system. This is understandable because in the satellite images of confluences it is impossible to differentiate bifurcations since from a plan view they all look as equal geometrical structures. Therefore, the study used elevation data got from Google Earth to determine flow courses and be able to differentiate them. Once confluences were identified, they were digitalized. This was done following the process that is hereunder described:

- Using the same Google Earth tool, the confluence geometry was demarked and processed in ArcGis (Fig. 6).
- The drawing was exported with kml extension
- Autocad (2014) software was used it to process the image and get a digital model with the plan view of the confluents' geometry.
- On the digital models we measured confluents' width and intersection angles (Fig. 7).

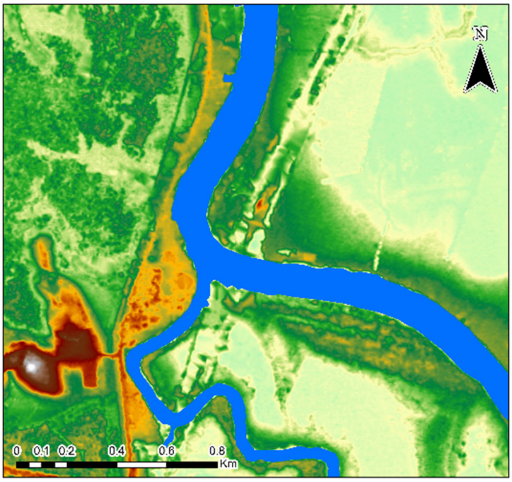


Fig. 6. Geometrical demarcation on satellite image

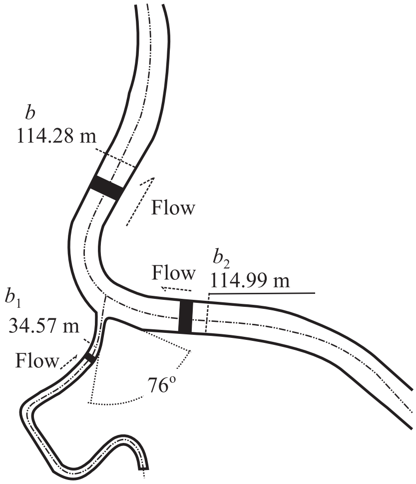


Fig. 7. Digital image processing

Similarity in Geometry Relationships

A classification based on the intersection angle (θ) of river confluences and confluents' mean width was proposed. Three dimensionless similarity parameters were generated from the rivers forming the confluence. That enabled us to see if there existed a similarity among confluences of different sizes.

The similarity relationships that were generated were the following:

Similarity relationship among confluent rivers,

$$R_0 = \frac{b_1}{b_2} \tag{1}$$

Similarity relationship between the branch of a tributary and the confluence outflow

$$R_1 = \frac{b_1}{b} \tag{2}$$

Similarity relationship between the branch of a large river and the confluence outflow

$$R_2 = \frac{b_2}{b} \tag{3}$$

These similarity relationships range between 0 and 1, thus indicating the similarity in size of the confluent rivers. Therefore, a value close to 1 is highly similar while a value close to zero presents little similarity. Sometimes the relations were greater than 1, this mean a bad election of the branches, in these case we change the arrangement to adjust this value.

Analysis

Initially, we analyzed simple data dispersion among similarity relationships (R_0, R_1 and R_2) and the intersection angle (θ) of confluences (Table 1). We used Excel software and generated trend graphs without found any behavior. Therefore, we did an exploratory analysis of data to know how many groups (clusters in statistical term) was adequate to detect differences among all the variables under the study. Cluster is defined as an aggrupation of all units (or objects) under one study, in such a way that all units or objects in the same group (this is a cluster) are similar. In other words, the groups may have similar values in all variables. With this grouping procedure (clustering), it is possible to get minimum square sum inside the groups (Sum of squares). In this sense, the clusters are homogenous in all variables under the study; hence, they can be used as units. In order to achieve it, we used the MiniTab 16® (2013) software. Four variables were assessed; θ, R_0, R_1 and R_2. With this type of analysis, the hypothesis was if it was possible to identify relations among variables. The key point here is to properly select the number of clusters. Consequently, we selected those that grouped the largest amount of observations in the least amount of groups, whereby we selected clusters 5, 6, 7, 8 and 9.

RESULTS

Dispersion analysis

Table 1. Concise confluence information

ID	b, m	b_1, m	b_2, m	θ, °	R_0	R_1	R_2
1	357.56	63.53	360.4	96	0.18	0.18	0.99
2	500.73	136.8	271.99	120	0.50	0.27	0.54
3	89.86	60.09	83.31	62	0.72	0.67	0.93
4	25.51	11.42	22.02	7	0.52	0.45	0.86
5	114.28	34.57	114.99	76	0.30	0.30	0.99
6	101.17	51.94	143.99	111	0.36	0.51	0.70
7	138.38	133.52	148.94	93	0.90	0.96	0.93
8	117.67	98.9	169.6	89	0.58	0.84	0.69
9	103.68	60.67	75.16	40	0.81	0.59	0.72
10	161.13	77.6	162.11	138	0.48	0.48	0.99
11	82.43	26.2	94.71	77	0.28	0.32	0.87
12	134.35	141.01	151.44	44	0.93	0.95	0.89
13	177.44	93.25	180.39	127	0.52	0.53	0.98
14	127.37	74.66	97.75	48	0.76	0.59	0.77
15	40.92	23.39	23.53	46	0.99	0.57	0.58
16	32.32	37.9	74.35	28	0.51	0.85	0.43

Table 1. cont.

ID	b, m	b_1, m	b_2, m	θ, °	R_0	R_1	R_2
17	44.35	40.18	40.64	28	0.99	0.91	0.92
18	54.8	52.36	54.88	54	0.95	0.96	1.00
19	45.21	19.98	47.85	91	0.42	0.44	0.94
20	65.27	55.08	57.84	51	0.95	0.84	0.89
21	20.83	15.12	23.07	77	0.66	0.73	0.90
22	82.79	28.12	85.56	68	0.33	0.34	0.97
23	44.3	26.1	26.57	18	0.98	0.59	0.60
24	23.4	7.69	29.15	108	0.26	0.33	0.80
25	85.9	51.19	79.01	95	0.65	0.60	0.92
26	180.55	78.35	93.63	48	0.84	0.43	0.52
27	339.94	106.72	185.62	64	0.57	0.31	0.55
28	106.44	47.24	75.78	47	0.62	0.44	0.71
29	137.73	68.04	68.72	50	0.99	0.49	0.50
30	98.66	65.6	77.23	64	0.85	0.66	0.78
31	219.59	36.18	293.49	64	0.12	0.16	0.75
32	34.44	24.26	36.66	106	0.66	0.70	0.94
33	30.25	10.54	23.47	158	0.45	0.35	0.78
34	32.78	18.13	32.56	114	0.56	0.55	0.99
35	75.85	40.05	46.1	149	0.87	0.53	0.61
36	52.26	15.78	55.62	36	0.28	0.30	0.94
37	77.92	32.79	71.13	144	0.46	0.42	0.91
38	79.79	22.42	66.81	86	0.34	0.28	0.84
39	126.43	48.31	161.49	118	0.30	0.38	0.78
40	144.09	79.79	122.37	92	0.65	0.55	0.85
41	134.25	52.14	73.21	26	0.71	0.39	0.55
42	199.38	52.61	167.82	94	0.31	0.26	0.84
43	61.19	42.44	68.01	98	0.62	0.69	0.90

Simple dispersion

In the first stage, all similarity relationships were plotted on the graph against the confluence intersection angle (Figures 6a, b and c). Then, polynomial trend type lines were adjusted without seeing any behavior pattern or dependence among variables; thereby we decided to make a multivariate analysis.

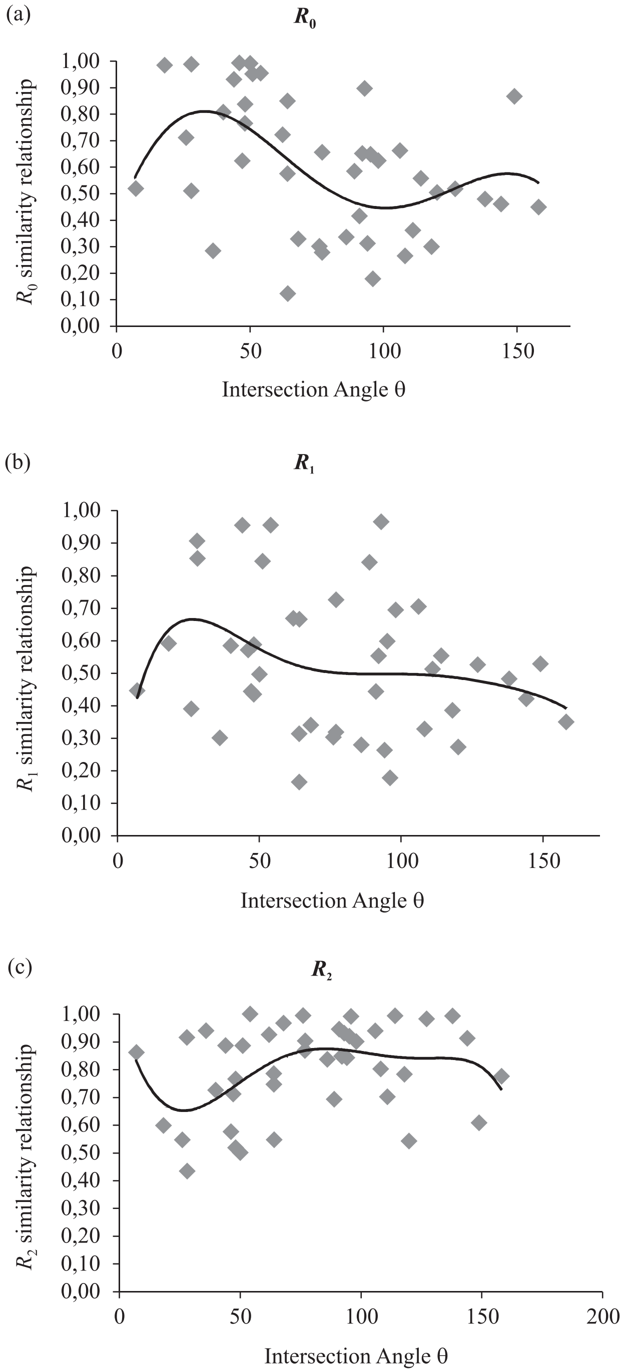


Fig. 8. Correlation among similarity relationships and intersection angle: a) R_0 vs θ, b) R_1 vs θ and c) R_2 vs θ

Multivariate analysis

We decided to use the multivariate analysis in seven clusters because the number of elements (observations) was more consistent in all of the groups (Table 2). If the number of clusters was larger, the classification did not improve (Table 3 and 4); on the contrary, if it decreased we found groups with only one element (Table 5 and 6). The Sum of Squares in the analysis was a sign of variation to the mean, and for this study it was considered as acceptable.

Table 2. Multivariate analysis results for 7 clusters

	Number of observations	Sum of squares	Average distance from centroid	Maximum distance from centroid
Cluster 1	2	1.527	0.874	0.874
Cluster 2	5	9.959	1.378	1.866
Cluster 3	9	6.653	0.777	1.428
Cluster 4	8	13.166	1.189	2.12
Cluster 5	7	3.208	0.633	1.08
Cluster 6	7	6.066	0.914	1.12
Cluster 7	5	2.257	0.621	1.076

Table 3. Multivariate analysis results for 5 clusters

	Number of observations	Sum of squares	Average distance from centroid	Maximum distance from centroid
Cluster 1	9	6.306	0.774	1.216
Cluster 2	4	5.65	1.176	1.469
Cluster 3	13	17.296	1.115	1.6
Cluster 4	11	18.314	1.209	2.157
Cluster 5	6	3.632	0.742	1.198

Table 4. Multivariate analysis results for 6 clusters

	Number of observations	Sum of squares	Average distance from centroid	Maximum distance from centroid
Cluster 1	2	1.527	0.874	0.874
Cluster 2	5	9.959	1.378	1.866
Cluster 3	13	17.296	1.115	1.6
Cluster 4	8	13.166	1.189	2.12
Cluster 5	7	3.208	0.633	1.08
Cluster 6	8	7.497	0.949	1.184

Table 5. Multivariate analysis results for 8 clusters

	Number of observations	Sum of squares	Average distance from centroid	Maximum distance from centroid
Cluster 1	2	1.527	0.874	0.874
Cluster 2	3	4.744	1.217	1.542
Cluster 3	9	6.653	0.777	1.428
Cluster 4	4	2.578	0.762	1.198
Cluster 5	7	3.208	0.633	1.08
Cluster 6	7	6.066	0.914	1.12
Cluster 7	5	2.257	0.621	1.076
Cluster 8	6	7.226	1	1.987

Table 6. Multivariate analysis results for 9 clusters

	Number of observations	Sum of squares	Average distance from centroid	Maximum distance from centroid
Cluster 1	2	1.527	0.874	0.874
Cluster 2	3	4.744	1.217	1.542
Cluster 3	7	2.667	0.569	0.922
Cluster 4	1	0	0	0
Cluster 5	7	3.208	0.633	1.08
Cluster 6	7	6.066	0.914	1.12
Cluster 7	5	2.257	0.621	1.076
Cluster 8	2	2.656	1.152	1.152
Cluster 9	9	8.404	0.95	1.237

Based on the results generated from the clusters, we made a second qualitative classification (visual) where the geometrical forms obtained from the clusters were evaluated. Thereby, from this analysis we got three groups that are shown in Figures 9–11.

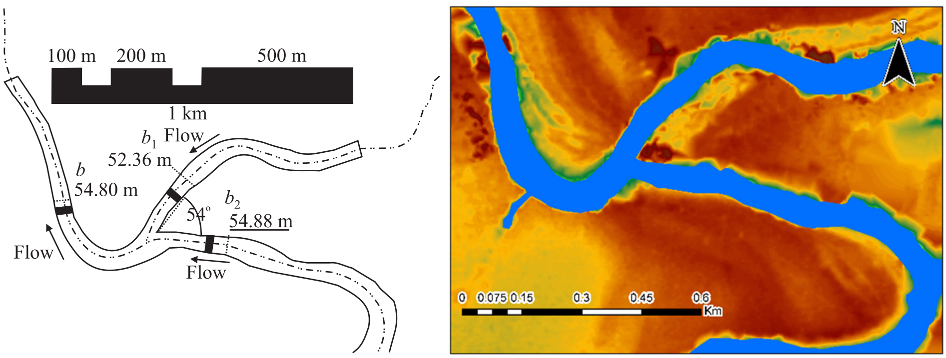


Fig. 9. Similarity in the width of the three tributaries with an intersection angle of less than 80°

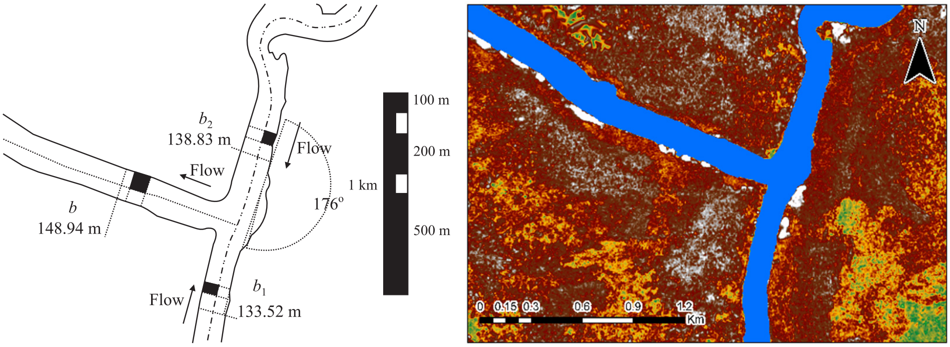


Fig. 10. Similarity in the width of the three tributaries with an intersection angle ranging from 80° to 160°

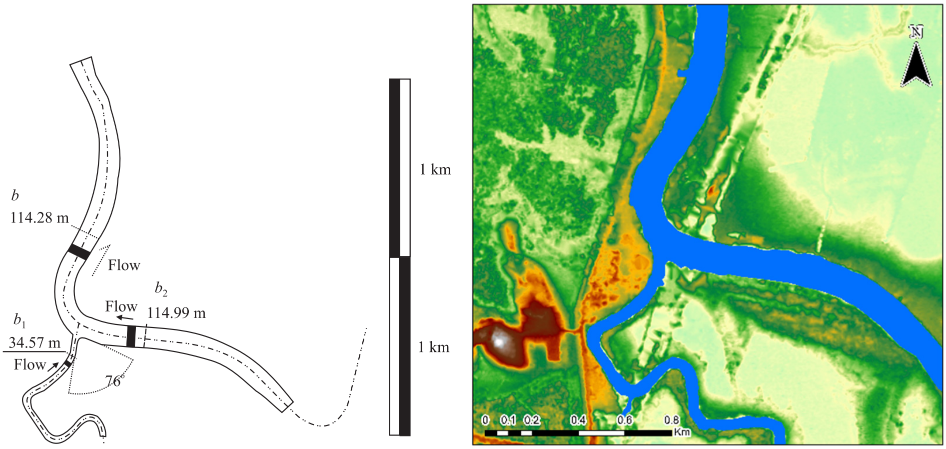


Fig. 11. Similarity in the width of the main river (the widest) and the outflow, with a secondary river (minor width) in the confluence. Its angle is less than 100°

By using this classification in localized confluences, the following three groups and their clusters were well delimited: Group I, clusters 7 and 4; Group II, cluster 6, 5 and finally Group III, clusters 3 and 2. In the following Table appear the aforementioned classifications.

Since in the statistical classification there are shear type milestones, we found slightly high values in a variable of the last three groups done, as for example, ID confluences: 29 and 30 in Group III, whose R_0 values are higher than most of the values in said group. This is because the function of the multivariate analysis that groups the observations of the group of most alike elements, consists in evaluating not only one but all of its variables

Table 7. Confluence classification in three groups

Group	ID	*b*	*b*1	*b*2	*θ*	*R*0	*R*1	*R*2	Cluster
I	7	138.38	133.52	148.94	93	0.90	0.96	0.93	7
I	12	134.35	141.01	151.44	44	0.93	0.95	0.89	7
I	17	44.35	40.18	40.64	28	0.99	0.91	0.92	7
I	18	54.8	52.36	54.88	54	0.95	0.96	1.00	7
I	20	65.27	55.08	57.84	51	0.95	0.84	0.89	7
I	4	25.51	11.42	22.02	7	0.52	0.45	0.86	4
I	9	103.68	60.67	75.16	40	0.81	0.59	0.72	4
I	14	127.37	74.66	97.75	48	0.76	0.59	0.77	4
I	15	40.92	23.39	23.53	46	0.99	0.57	0.58	4
I	16	32.32	37.9	74.35	28	0.51	0.85	0.43	4
I	23	44.3	26.1	26.57	18	0.98	0.59	0.60	4
I	28	106.44	47.24	75.78	47	0.62	0.44	0.71	4
I	41	134.25	52.14	73.21	26	0.71	0.39	0.55	4
II	6	101.17	51.94	143.99	111	0.36	0.51	0.70	6
II	10	161.13	77.6	162.11	138	0.48	0.48	0.99	6
II	13	177.44	93.25	180.39	127	0.52	0.53	0.98	6
II	24	23.4	7.69	29.15	108	0.26	0.33	0.80	6
II	33	30.25	10.54	23.47	158	0.45	0.35	0.78	6
II	37	77.92	32.79	71.13	144	0.46	0.42	0.91	6
II	39	126.43	48.31	161.49	118	0.30	0.38	0.78	6
II	5	114.28	34.57	114.99	76	0.30	0.30	0.99	5
II	11	82.43	26.2	94.71	77	0.28	0.32	0.87	5
II	19	45.21	19.98	47.85	91	0.42	0.44	0.94	5
II	22	82.79	28.12	85.56	68	0.33	0.34	0.97	5
II	36	52.26	15.78	55.62	36	0.28	0.30	0.94	5
II	38	79.79	22.42	66.81	86	0.34	0.28	0.84	5
II	42	199.38	52.61	167.82	94	0.31	0.26	0.84	5
II	1	357.56	63.53	360.4	96	0.18	0.18	0.99	1
II	31	219.59	36.18	293.49	64	0.12	0.16	0.75	1
III	3	89.86	60.09	83.31	62	0.72	0.67	0.93	3
III	8	117.67	98.9	169.6	89	0.58	0.84	0.69	3
III	21	20.83	15.12	23.07	77	0.66	0.73	0.90	3
III	25	85.9	51.19	79.01	95	0.65	0.60	0.92	3
III	30	98.66	65.6	77.23	64	0.85	0.66	0.78	3
III	32	34.44	24.26	36.66	106	0.66	0.70	0.94	3
III	34	32.78	18.13	32.56	114	0.56	0.55	0.99	3
III	40	144.09	79.79	122.37	92	0.65	0.55	0.85	3
III	43	61.19	42.44	68.01	98	0.62	0.69	0.90	3
III	2	500.73	136.8	271.99	120	0.50	0.27	0.54	2
III	26	180.55	78.35	93.63	48	0.84	0.43	0.52	2
III	27	339.94	106.72	185.62	64	0.57	0.31	0.55	2
III	29	137.73	68.04	68.72	50	0.99	0.49	0.50	2
III	35	75.85	40.05	46.1	149	0.87	0.53	0.61	2

CONCLUSIONS

The use of satellite images is a recent tool used for research purposes. Its use in river geometrical classification enabled us to recognize the different geometries of river systems in the State of Tabasco in Mexico. We identified deviations, branches, confluences and curves. Particularly in the case of confluences, it was possible to identify and classify them based on the plan view of their geometry.

Therefore, we identified and digitalized a total of 43 confluences. The classification was done from the quantitative and qualitative perspective. First, a statistical analysis was done to assess 4 control variables proposed (R_0, R_1, R_2 and θ), thus getting a set of 7 clusters (Groups). From this first classification, we visually assessed geometrical similarities among clusters, thereby determining the existence of a geometrical similarity among cluster groups. At the end we arrived to a final classification of three (3) types of confluences: I. Similarity among its three rivers (R_0, R_1 and R_2 and an intersection angle of less than 80°; II. Similarity among its three rivers (R_0, R_1 and R_2) and an intersection angle ranging from 80° to 160°; and III. Similarity among the main river, the outflow and an angle of less than 100°.

Consequently, there are at least three types of geometrical patterns among the different confluences in the State of Tabasco. It is recommendable to conduct both hydraulic and sedimentological complementary studies, to better understand the holistic behavior of confluences and verify that said confluences not only present similar geometrical characteristics but also similar or slightly different hydraulic functions.

Once the above mentioned is achieved, the next step would consist of taking measures and conducting specialized studies (flow rate, flow depth, cross section, type of materials, etc.) that confirm the confluence type behavior pattern.

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KLASYFIKCJA ZDJĘĆ SATELITARNYCH ZBIEGÓW RZEK

Streszczenie. Zbieg rzek jest definiowany jako punkt spotkania dwóch lub więcej rzek, które dają początek nowej rzece. To połączenie się rzek powoduje, że parametry geometryczne, szczególnie szerokość i kąt przecięcia kształtują się w zależności od charakterystycznych cech zlewających się rzek. Opierając się na tym poglądzie, jak również na dostępnych zdjęciach satelitarnych sklasyfikowano w tej pracy 43 zbiegi rzek usytuowane w Tabasco (Meksyk). Kluczowe elementy stanowiły geometria (widok z góry) oraz kąt przecięcia, natomiast klasyfikację wykonano na podstawie stosowanych wielowymiarowych analiz statystycznych. Wyniki przedstawiono w trzech grupach: I. Podobieństwo między szerokościami trzech rzek i kąt przecięcia mniejszy niż 80°; II. Podobieństwo między szerokościami trzech rzek i kątem przecięcia między 80° a 160°; III: Podobieństwo między szerokością głównej rzeki (największej rzeki w zbiegu) oraz zbiegu rzek i kąt przecięcia większy niż 100°. Po przeprowadzeniu tej klasyfikacji, następnym krok to wykonanie zarówno hydraulicznych, jak i sedymentologicznych badań, pozwalających zrozumieć integralne zachowanie się zbiegających się rzek oraz zweryfikować proponowaną klasyfikację nie tylko pod kątem podobieństw geometrycznych, ale także działań hydraulicznych i sedymentologicznych, które również wykazują podobieństwa. Ze względu na trudności związane z badaniem wielu zbiegów rzek najlepiej byłoby wybrać ich przedstawiciela i dokonać jego analizy. W niniejszej pracy przedstawiliśmy postępowanie alternatywne, które może być użyteczne dla pracowników naukowych i inżynierów, jak również studentów zainteresowanych badaniem zbiegów rzek.

Słowa kluczowe: geometria rzek, wielowymiarowa analiza statystyczna, połączenie rzek

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