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# AQUATIC MACROINVERTEBRATES INTEGRATED INTO THE BIOTIC WATER QUALITY INDEX BMWP/COL: A FORMAL KNOWLEDGE REPRESENTATION BASED ON ONTOLOGIES

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## ABSTRACT

The diversity of aquatic macroinvertebrates at the family level; has been validated as indicators of water quality and adjusted to biotic indices. The Biological Monitoring Working Party (BMWP), established in England in the 1970s, was adapted in Colombia in specific basins in 1997, and has been useful for the evaluation of freshwater ecosystems. The present research was based on the creation of an ontological system of aquatic macroinvertebrates integrated to the BMWP/Col. index, with the purpose of organising, storing and modelling water quality knowledge from the aquatic macroinvertebrate domain useful for Colombia. The conceptualisation and creation of the ontological model was developed with the *Methontology* methodology, which allowed identifying the activities and tasks that formalised the system, being codified in an ontological language OWL, through the use of the Protegé editing tool. The results achieved with the ontological model enable the valuation and environmental management of water resources to be channelled, guaranteeing rapid and timely information, and projecting an improvement in future water quality characterisation studies.

## INTRODUCTION

Artificial Intelligence (AI) according to Rich E. and Knight (1994) studies how to make machines perform tasks better than humans. The problems addressed by AI are broad, knowledge representation is one area of Artificial Intelligence, which can be shown to be the art of creating, or emulating, intelligent behaviour (Rolston & Perez Gama, 1990). Representation is a technique used in Knowledge-Based Systems, which allow you to structure knowledge of a particular domain in a knowledge base and act as if you were an expert in the area. The Semantic Web is an extension of the web endowed with meaning; within the semantic web architecture are ontologies, which allow knowledge to be better structured so that its meaning can be understood.

Ontologies through descriptive logic can infer knowledge of an object of study. Logic is the essence of intelligence (Rich & Knight, 1994), formal logic in the wake of philosophy was one of the oldest forms of knowledge representation (Rolston & Perez Gama, 1990). Descriptive logics are generally used to represent taxonomic knowledge, integrating objects, classes and relations. Constructors such as conjunction $C \cup D$ and disjunction $C \cap D$ knowledge bases are formed by the Abox and the Tbox (Baier Aranda, 2012). Ontologies can be used to model knowledge as well as to store information; traditional databases differ from an ontology in the associated semantics, so that inference and reasoning can be performed with it (Garrido Sánchez, 2012). It is expressed, in this way, that ontologies are real applications, resources that contain formal knowledge of a particular domain or the interaction between domains (Mahesh, 1996), in this way, ontologies can provide a way of sharing knowledge using a common vocabulary, as they incorporate tags that enable the semantic component (Garrido & Requena Ramos, 2010).

Building Domain Ontologies is one of the major vocations and interests for the WS (Semantic Web), where the intended use is to formalise an area of knowledge. The ontology itself will not specify which concepts can be reused in other domains nor how this would be done (Morales et al., 2017). Each ontology prototype generated becomes a first approach to ontology-based knowledge representation, which evolves as knowledge is reused. There is no single correct way to model a domain, ontology development is a process (Noy & McGuinness, 2001).

Water quality studies based on physicochemical factors, biotic or ecological components, are a fundamental baseline for the evaluation and environmental management of water resources for formulation and management purposes, whose final purpose is the conservation of the resource, aquatic life, its use and management by the human species. In Colombia, different environmental norms, laws or decrees of great relevance have been issued with the purpose of conserving and protecting resources. This research shows the development of the ontology of aquatic bio-indicators adapted to the BMWP/Col (Pérez, 2003). It is seen as a knowledge-based system that starts with the conceptualisation of the knowledge and then formalises it, followed by the construction and finally the testing of the system. The conceptualisation describes the regulations of the subject, the quality criteria, the aquatic macro-invertebrates and their use as bio-indicators of water quality, among other aspects; In the formalisation, the stages developed for the structuring of the knowledge of the object of study are stated, which is codified for its construction through the Protegé tool, where the ontology domain is integrated, the biotic component of water quality through the identification and weighting of macroinvertebrates tolerant or sensitive to pollution, adapted to the BMWP Colombia biotic index (BMWP Colombia (Pérez, 2003)). In this way, the information can be centralised and used without geospatial limits, accurately and efficiently, contributing to the consolidation of a better use of biotic indicators of water quality in specific basins in the country.

## METHODOLOGY

### *Ontology planning*.

For the development of the research, the methodology used was Methontology (Figure 1), which has a life cycle based on the evolution of prototypes, developed at the Polytechnic University of Madrid (Fernández-López et al., 1997). As shown in Table 1, all administration and support activities are performed in parallel with the development activities during the whole life cycle of the Ontology (Flores-Vitelli, 2011). In the framework of the knowledge immersed in the ontology (Velásquez et al., 2011) was developed according to two instruments: the Documentary Analysis and the interview, being the basis for the deepening of the domain, task approached with experts in the areas of design and ontology models (expert systems) and hydrological quality indicators.

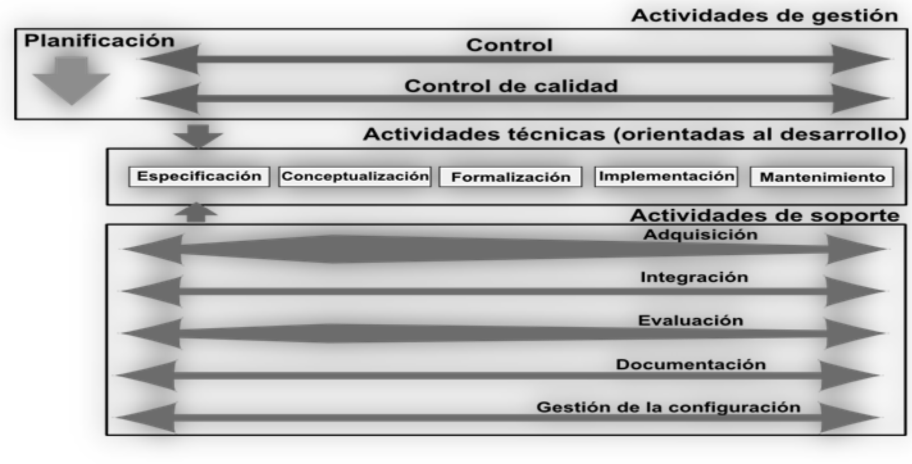


**Figure 1**. Methontology methodology. Source: (Fernández-López et al., 1997)

**Table 1.** Ontology development activities

| **PA Activities (Project Management)** | |
|---|---|
| Activity | Target |
| Planning | All tasks related to planning and associated technological and human resources are carried out. |
| Control | Specify mechanisms to ensure the accomplishment of a task. |
| Quality | Specifying quality standards |
| **Development Activities** | |

| Activity | Target |
|---|---|
| Specification | Document that indicates who the users of the ontology would be, the objective it fulfils, its scope, goals and the degree of formality of the ontology. |
| Conceptualisation | Conceptual model of the object of study. |
| Formalisation | Transforming the conceptual model into a semi-computable model |
| Integration | Integrate existing ontologies to ensure knowledge reuse. |
| Implantation | Use of formal language for ontology building |
| Maintenance | Update the ontology when required. |
| **Integration Activities** | |
| Activity | Target |
| Knowledge acquisition | Acquire knowledge through the application of appropriate techniques. |
| Evaluation | Review compliance with the Ontology. |
| Documentation | Ontology support documents |

**Source:** (Flores-Vitelli, 2011).

The **Specification** of Requirements was addressed by indicating the ontology's end-user information, purpose, scope, goals and degree of formality (Table 2), where emphasis was placed on the integration of aquatic macroinvertebrates as indicators of water quality biotic indices (BMWP/Col), with the convention of centralising, storing and modelling the knowledge of water valuation in Colombian watersheds.

**Table 2.** Ontology requirements specifications.

| **Domain** | **Aquatic indicators of aquatic macroinvertebrates (Taxonomic Families) adjusted to BMWP/Col.** |
|---|---|
| **Purpose** | Integrate aquatic indicators (macroinvertebrates) to biotic quality indices, in order to systematically adapt and organise the terminology of this domain, which explicitly allows solving the problem of dispersed information on aquatic insects, thus being able to centralise, store and model knowledge in an agile and efficient way for the identification and assessment of water quality. |
| **Outreach** | **Competence Questions**<br>1. Knowing the families of macroinvertebrates for the BMWP Which order does it belong to?<br>2. Knowing the characteristics of a specimen, which family does it belong to?<br>3. What aquatic organisms are present to determine water quality?<br>4. How do agencies relate to the quality weighting in the BMWP?<br>5. What different and common characteristics are relevant for |

| | |
|---|---|
| | the identification of aquatic insects?<br>6. How would taxonomic characters be determined in common language for the identification of taxa?<br>7. Knowing the Body shape, Head, Eyes present simple or compound, wings, larval stage, antennae, abdomen, presence of gills, legs, gills, thorax, palps, filaments, mandibles, ocelli, flagella, spiracles, which families are identified?<br>8. Knowing the characteristics of aquatic insects, which family group does it belong to? |
| **Users** | It is up to the experts, who are the implementing members of the project, the scientific and academic community and those interested in the topic of biotic indicators of water quality for this domain. |

***Conceptualisation and formalisation of aquatic macroinvertebrates integrated into the biological index BMWP/Col (Biological Monitoring Working Party score).***

In Colombia, for water resources, given the great importance of the case and the accelerated deterioration of this resource, there are regulations such as Decree 1594 of 1984, which sets out the quality criteria for the planning, use and proper management of water resources; Decree 3930 of 2010, opens the way for the Ministry of Environment and Sustainable Development (MADS) to issue the proposed Guide for the Formulation of the Water Resource Management Plan (PORH), focused on the management of water resources for the preservation and guarantee of a resource suitable for humanity (MADS, 2014). According to these premises of the norms; the MADS, exposes in an explicit way in the PORH the use of the index BMWP/Col, widely used in the country, counting to obtain a wide ecological diagnosis of the evaluated system.

The BMWP/Col. index, taxonomically related to the hierarchy of families (Table 3), indicates the strict limits of water quality and constitutes one of the most important allied indices for ecological assessment and for the construction of the biological quality map of surface streams (Roldán & Ramírez, 2008, p. 343). Its values range from greater than 100 (very good quality) to less than 15, reflecting very critical conditions (Pérez, 2003). The method only needs to go down to the level of families and the data are qualitative (presence/absence), although its adaptation to specific catchments is based on the abundance of the most abundant families for this purpose. The score ranges from 1 to 10, according to the tolerance of the different groups to organic pollution. The most sensitive families, such as Perlidae and Oligoneurridae, receive a score of 10, while the most pollution tolerant families, such as Tubificidae, receive a score of 1 (Roldán & Ramírez, 2008, p. 342).

**Table 3.** Taxonomic families and Presence/Absence Score for the BMWP/Col Index

| Taxonomic Families | Score |
|---|---|
| Anomalopsychidae, Atriplectididae, Blephariceridae, Ptilodactylidae, Chordodidae, Gripopterygidae, Lampyridae, Odontoceridae, Perlidae, Polymitarcyidae, Polythoridae, Psephenidae | 10 |
| Coryphoridae, Ephemeridae, Euthyplociidae, Gomphidae, Hydrobiosidae, Leptophlebiidae, Limnephilidae, Oligoneuriidae, Philopotamidae, Platystictidae, Polycentropodidae, Xiphocentronidae | 9 |
| Atyidae, Calamoceratidae, Hebridae, Helicopsychidae, Hydraenidae, Hydroptilidae, Leptoceridae, Limnephilidae, Lymnaeidae, Naucoridae, Palaemonidae, Planorbidae (where Biomphalaria is dominant), Pseudothelpusidae, Saldidae, Sialidae, Sphaeriidae | 8 |
| Ancylidae, Baetidae, Calopterygidae, Coenagrionidae, Dicteriadidae, Dixidae, Glossosomatidae, Hyalellidae, Hydrobiidae, Hydropsychidae, Leptohyphidae, Lestidae, Pyralidae, Simuliidae, Veliidae, Veliidae | 7 |
| Aeshnidae, Ampullariidae, Caenidae, Corydalidae, Dryopidae, Dugesiidae, Elmidae, Hyriidae, Limnichidae, Lutrochidae, Megapodagrionidae, Mycetopodidae, Pleidae, Staphylinidae. | 6 |
| Ceratopogonidae, Corixidae, Gelastocoridae, Glossiphoniidae, Gyrinidae, Libellulidae, Mesoveliidae, Nepidae, Notonectidae, Tabanidae, Thiarida. | 5 |
| Belostomatidae, Chrysomelidae, Curculionidae, Ephydridae, Haliplidae, Hydridae, Muscidae, Scirtidae, Empididae, Dolichopodidae, Hydrometridae, Noteridae. Sciomyzidae. | 4 |
| Chaoboridae, Cyclobdellidae, Hydrophilidae (larvae), Physidae, Stratiomyidae, Tipulidae. | 3 |
| Chironomidae (when not the dominant family, if dominant it is 1), Culicidae, Psychodidae, Syrphidae. | 2 |
| Tubificidae | 1 |

**Source**: (Roldán & Ramírez, 2008, p. 346).

Given the requirements of the BMWP/Col. method, based on aquatic macroinvertebrates, Table 4, as presented in Roldad and Ramirez, (2008, p. 343), "shows the five water quality classes resulting from the sum of the scores obtained by families found in a given ecosystem. According to the BMWP/Col. score obtained in each situation, the different water classes are graded, assigning each one a certain colour, which corresponds to the colour used to mark the rivers and streams on the map of the region studied" Given the ease of the index, in Colombia there is a great acceptability in the use of organisms as indicators of the biotic quality of freshwater ecosystems, with the work of (Roldán & Ramírez, 2008); (Cardoso et al., 1997); Zamora, (1999); Álvarez, (2005); Quiñones and Roldan (1998), studies that have allowed progress to be made in this aspect, seeking to unify biotic quality indices adapted for the country.

**Table 4.** Quality classes, significance of B.M.W.P.P/Col values

| **Value (BMWP/Col)** | ***Class*** | **Quality/Colour** | **Meaning** |
|---|---|---|---|
| > 150 | I | Good | Very clean waters |
| 101-120 | | | Unpolluted or not significantly altered waters |
| 61-100 | II | Acceptable | Slightly contaminated: some contamination effects are evident. |
| 36-60 | III | Doubtful | Moderately polluted waters |
| 16-35 | IV | Critique | Heavily polluted waters |
| < 15 | V | Very critical | Heavily polluted water, critical situation |

**Source:** Modified from (Roldán & Ramírez, 2008, p. 346).

"The use and importance of macroinvertebrates as indicators of water quality is based on the fact that these organisms occupy a habitat to whose environmental requirements they are adapted; any change in environmental conditions will therefore be reflected in the structures of the communities that inhabit it" (Roldán & Ramírez, 2008, p. 339). Hence the relevance of aquatic macroinvertebrates, they are considered indicators of water quality, as they are witnesses of the physico-chemical conditions of the ecosystem, most of them spend a life cycle in the water; the community of indicator organisms is evolutionarily adapted to the aquatic environmental conditions that allows them to survive over time within limits of tolerance that physiologically manifest themselves in their ecological optimum or dismal (Jaramillo, 2006).

Given the characteristics of freshwater systems, from very oligotrophic, mesotrophic to eutrophic or simply clean, moderately polluted, highly polluted or critical waters, they present a macroinvertebrate community that determines their quality (Roldán & Ramírez, 2008, p. 340). Understanding the complexity of an indicator organism, biological methods for the determination of water quality have been integrated throughout history and have been used in Europe, the United States and Canada since the beginning of the century (Pérez, 1999), this has given the important recognition of the great value of bioindication as a method for assessing water quality; aquatic macroinvertebrates, an integration of populations from different families, establish an unequivocal indicator of the conditions prevailing in a water body (Pérez, 1999). In this sense, indicator organisms correspond to those taxa that are sensitive or tolerant to pollution by one or several physico-chemical conditions. The use of bioindicators is appropriate and easy to manipulate in water quality monitoring; given these premises, indicator organisms are defined as the presence of a particular species, which demonstrates the existence of certain conditions in the environment, while their absence is the consequence of the alteration of those conditions (Arango, 2003).

## RESULTS

### *Construction of the ontology.*

The selection and compilation of the information through the specialised literature in the documentation stage and the interviews, allowed for a successful ontology Specification. The ontology specifications were treated as Requirements, as shown in table 2, where the information on the ontology end-users, purpose, scope, goals and degree of formality are indicated.

Given the requirements of the model generated from the selected information, the conceptualisation included systematically generating the tasks that led to building the prototype, from a conceptual model to a semi-computable model, being the most important activity of the designed system, which corresponds to formalising and implementing the ontology. Table 5 shows a synthesis of the Glossary of Terms, synonyms, acronyms, description that was integrated in the ontology through the concepts, attributes, relation, constants and instances. This allowed us to choose the most appropriate common language to formalise the model in the Protege Software.

**Table 5.** Summary of glossary of terms.

| Name | Description | Type |
|---|---|---|
| Larva | How insects hatch from eggs. They feed differently from the adult | Class |
| Family | A taxonomic hierarchy of classification that groups more than one organism with common characteristics. | Instance |
| Gills | Body wall evaginations Respiratory organ of aquatic macroinvetebrates, consisting of thin membranes through which water slides, promoting oxygen exchange. | Class attribute |

The Taxonomy of Concepts was built from the hierarchy (taxonomic characteristics of Families) between concepts that were integrated in the Protégé OWL prototype, which allowed the properties of the macroinvertebrate families to be related through their characteristics grouped alphabetically in the glossary of terms generated. Figure 2 shows a view of the taxonomy of classes that make up the Ashnidae family, as generated by the OntoGraf plugin of the software.

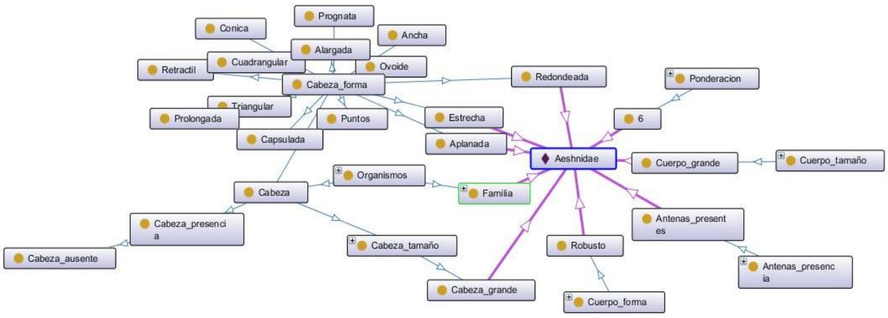


**Figure 2.** Hierarchy of concepts of the main properties and characteristics for the Family Aeshnidae.

The construction of the concept dictionary and the binary relationship diagrams (table 6), were built from the concepts generated in the glossary of terms, the relationships between concepts, instances and attributes of classes were determined, which coded and integrated in Protégé and associated interactions from the characteristics (properties) of each concept or individual, order and integrated family (Figure 2).

**Table 6.** Synthesis of Taxonomy of concepts, binary realisations and Attributes of classes that are integrated in Protege.

| **Taxonomy of concepts** | | | | | |
|---|---|---|---|---|---|
| **Concept** | **Instance** | **Class attribute** | **Relation** | **Destination Concept** | **Inverse relationship** |
| Order | Ephemeroptera | Name | Composed_of | Family | Pertence_a |
| Family | Oligoneuriidae | Name | Composed_of | Character | Belongs_to |
| Body | Oligoneuriidae | Name | Form_of | Family | Type_of |
| **Binary relationships** | | | | | |
| **Name of relationship** | | **Source concept** | **Destination Concept** | **Card** | **Inverse relationship** |
| Composed_of | | Order | Family | 1:n | Pertence_a |
| It has | | Thorax | Retractable | 1:1 | Are_part_of |
| Formed_by | | Abdomen | Guts | 1:1 | Part_of_form |
| **Class attribute** | | | | | |
| **Name** | | **Concept** | **Type of value** | **Value** | |
| Head | | Family | String | Flattened, rounded, ovoid, conical etc. | |
| Ocelo | | Class | String | Present/Absent | |
| Body | | Class | String | With or without shell, segmented or not, flattened, cylindrical, suction cupped | |

| | | | |
|---|---|---|---|
| | | | or not |

On the other hand, as can be seen in the system of table 6, the attributes of classes emanating from the dictionary of concepts, which by binary relationships are integrated into the software to give semantics to the ontology, which is the common language to give simplicity to search the stored information; allowing the attributes of instances the explicit description of the instances of a concept and its query value (Figure 3 and 4). Based on the concepts of each individual, each taxa, and the BMWP/Col index, it is possible to define the conceptual model, which from the instances was defined for each class in the Ontology, built with experts, which is expressed by exposing its name, the classes or concepts to which it belongs, the attributes and the values of those attributes as shown in table 5.

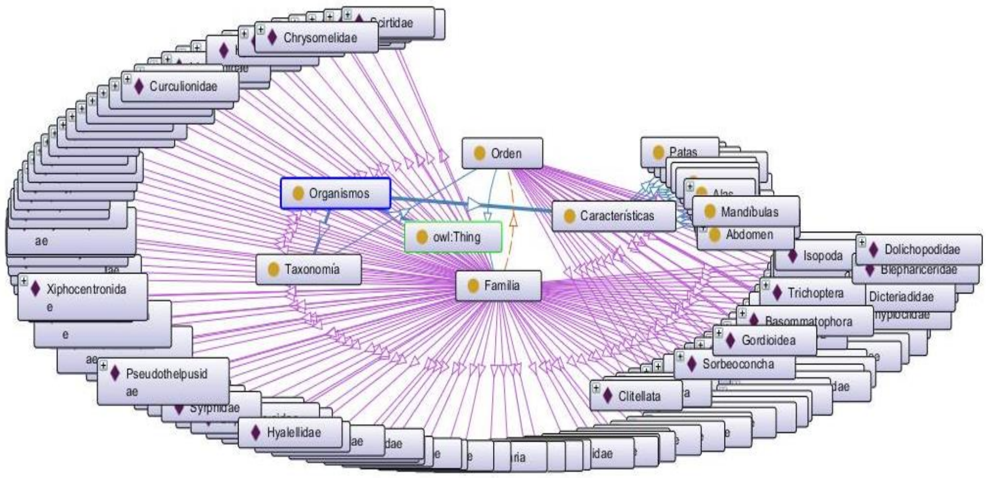


**Figure 3.** Taxonomy view of concepts and binary relations generated in the OntoGraf plugin.

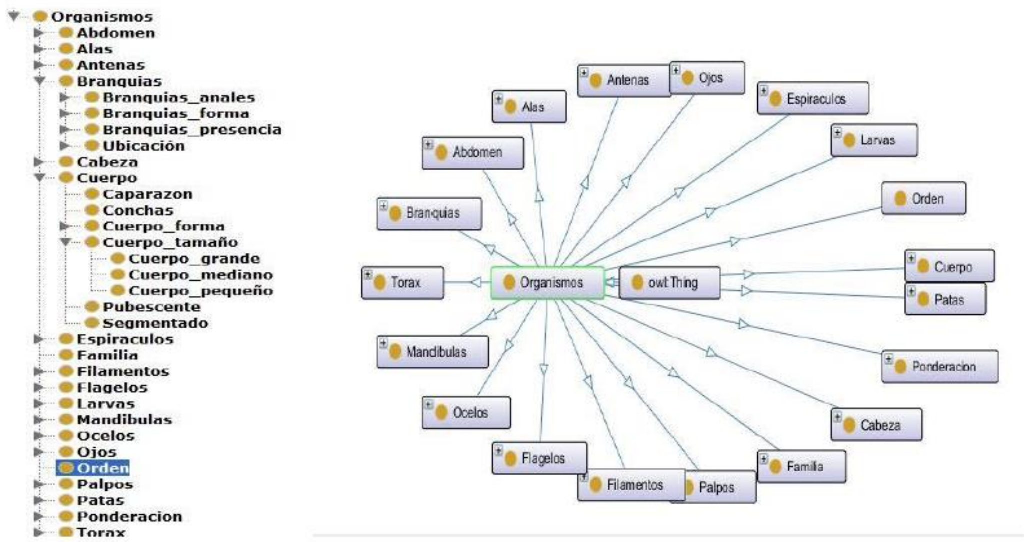

**Figure 4**. Overview of the taxonomy of concepts and binary relations generated in the OntoGraf plugin, related to the major group (order) and characteristics for each family.

It is expected that an ontological system of water quality indicators based on aquatic macroinvertebrates will meet the expectations of the specifications and requirements set, in terms of consultation and identification of families in relation to their characteristics and their integration into the BMWP/Col. To assess the quality of the water resource, for this specific case the constants and formal axioms were defined, as well as the rules that must be fulfilled within the ontology. In this aspect, based on the concepts described in the dictionary, some families share common characteristics that cannot be changed, which correspond to constant properties or characteristics; however, on the other hand, some of the rules described specify that a family cannot be in two or more of a larger group (table 7). In this case, the ontology generates the precision according to the axioms and rules defined and inserted to each particular case.

**Table 7.** Synthesis of axioms and rules of the ontology

| **Name** | **Description** | **Concept** | **Relation** |
|---|---|---|---|
| Order | A family can belong to only one order | Aquatic indicator | Belongs |
| Family | A family can belong to only one order | Order /Family | Belongs |
| Instances | A characteristic may be shared by several families belonging to the order and some are unique to one family. | Order/Family/ Character | Belongs |

In Figure 5 and 6, an overview of the storage of knowledge associated with the observable characteristics that allow the identification of each organism and the assessment of water quality can be seen as described by (Pérez, 2003). The first approach for the bioindication of water quality in Colombia was adapted in the first approximation. This association is done at the level of classes, instances and relationships that is reached in the integration and implementation stage from its codification in Protégé; once all possible instances are filled for each of the associated characteristics, it allows the identification of the instances of the characteristics within each instance of the concept of aquatic macroinvertebrate family.

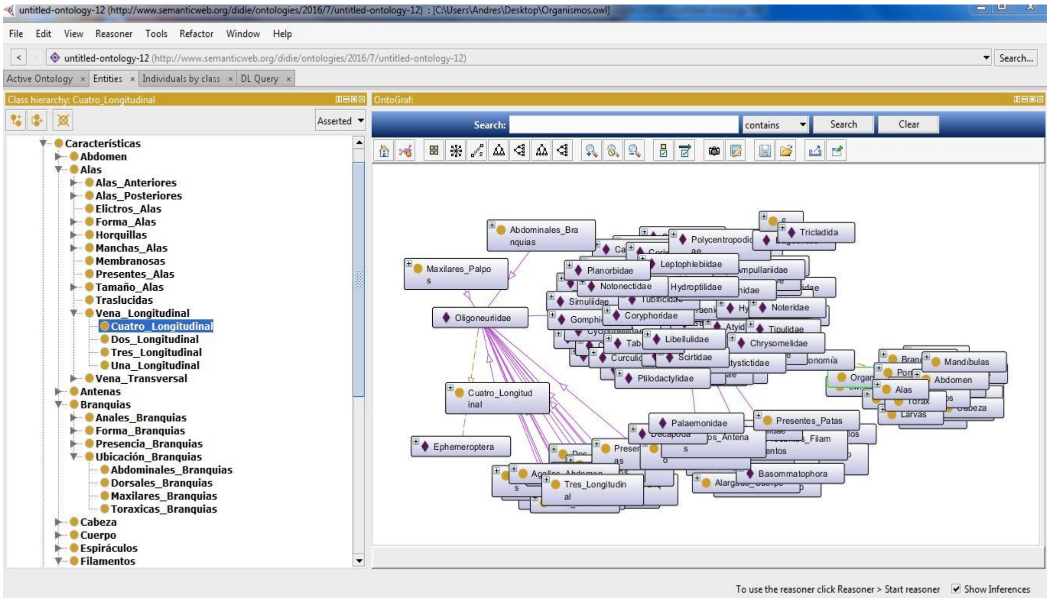


**Figure 5.** Details of the observable characteristics in the classification of organisms.

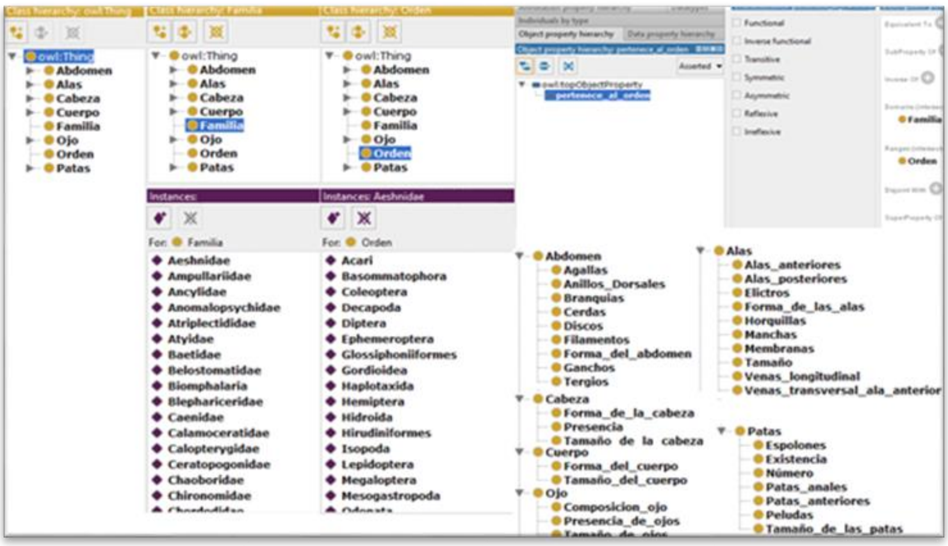


**Figure 6.** Overview of the relations associated with the knowledge associated with the observable characteristics of each macroinvertebrate.

Once the ontology is encoded in the Protege tool, its evaluation and documentation is done from the standard web application generated in Java, which allows users to share, browse and edit the ontology, providing a collaborative environment that can help communities in the development of ontologies. In this aspect, as shown in figure 5, there is a home section, which visualises the search engine for the identification from families or from main observable characteristics in common language of aquatic macroinvertebrates that integrate the ontology, being used at the level of experts or people related to the subject, without a high level of taxonomical knowledge of these organisms.

## CONCLUSIONS

Given the demands of environmental assessment and management at present, for the purposes of watershed planning and conservation. View of the need for a useful, simple and effective tool to determine water quality. An application is presented, an intelligent system based on ontologies whose specific domain is aquatic macroinvertebrates as indicators of quality, a system that stores relevant information on these organisms adjusted to the BMWP/Col Biotic Index.

The ontology developed, systematically organises the domain terminology, explicitly allowing to solve the problem of dispersed information of aquatic insects, thus being able to centralise, store and model the knowledge in an agile and efficient way for the identification and evaluation of water quality. Therefore, the ontology becomes a support tool for channelling solutions to this area of knowledge into future water quality studies.

On the other hand, the ontology will allow in the future to be modified or adapted to the requirements; this with the purpose of adapting it to the specific basins of the country, supporting in a beneficial way the needs for the formulation and management, since it would have a standardised repository of the biotic quality bio-indicators, becoming an allied tool to save and better channel the available resources in the environmental management, monitoring, surveillance and control of the contamination or deterioration of the water resource.

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