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ORIGINAL ARTICLE

Novel approach for issues identification in transboundary water management using fuzzy c-means clustering

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Abstract

Rivers, a major freshwater resource, are transboundary in nature (310 international basins) and are not governed by any water agreements. Scientific knowledge based on transboundary water resources is confined; hence, the identification of "knowledge gaps" to smoothen decision making in water management is necessary. To figure out the issues that affect water sharing is deemed important. This paper highlights the core issues involved in transboundary water management and prioritizes the identified issues using fuzzy c-means clustering algorithm. A group of 30 experts from various fields were consulted to rank the issues which were clustered to determine the prioritized rank. In a hypothetical basin affected by all the transboundary issues, flood control and benefit sharing are rated with very high importance. Prioritization would help in the identification of issues of high relevance that affect water sharing. This may facilitate efficient water sharing agreements among riparians and be useful in international water governance.

Keywords Transboundary water resources · Water management · Fuzzy c-means clustering · Cluster center · Prioritization · Riparians

Introduction

Unlike international disputes over other natural resources such as oil, there is no viable alternative to water. Without requisite quantity or quality of water, economic development as well as agricultural production would grind to a halt. This would lead to greater human suffering and threaten societal stability. Humanity's primary sources of water are freshwater rivers. Most of the freshwater rivers are transboundary in nature, i.e., they cross at least one political border, either a border within a nation or an international boundary. According to the Transboundary Freshwater Dispute Database (TFDD), the world has 276 international river basins (TFDD 2012) updated to 310 international river basins in 2017 (https://transboundarywaters.science.oregonstate.edu/content/data-and-datasets). More than 45% of the land surface on the Earth is covered by transboundary international river basins (Loucks and van Beek 2005). As the transboundary waters flow through various sovereign nations, they create social, economic, and hydrological interdependencies. Though international rivers can be a potential source of conflict, they still create possibilities as well as opportunities for cooperation. Successful transboundary water management promotes economic growth alongside regional peace and security which can thwart the much-anticipated water wars (Rai et al. 2017a, b).

In the absence of cooperation over the shared resources, each state must use the water in the river to its best advantage before it crosses international borders and becomes unreachable. Because of this, transboundary rivers can be potential loci for conflict over the use of the shared river. Scientific knowledge based on transboundary water management is more often fragmented which mostly considers specific cases and more particularly deals with specific key issues rather than covering a range of issues. Transboundary water management lacks inter-issue coordination and cross-sectoral management. This is easily visible in any international water treaties which generally discuss only a few issues from a range of issues. For example, the Indus water treaty deals with water quantity, the Danube River

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Agreement deals with water quality, and the Columbia River Agreement deals with flood control and hydropower. Hence, there is a growing need to take a holistic view of the range of issues involved in transboundary water management (Rai et al. 2016). This may supplement policy makers with more polished and informed decision-making opportunities in international water management.

The major thrust of the paper is on the prioritization of issues using FCM clustering and the idea is to propagate the use of fuzzy methodology in transboundary water management. Fuzzy logic approach has been used by numerous scholars in the fields not limited to medical diagnosis, data mining, information technology, robotics, water quality assessment, hydrology, reservoir operation, flood forecasting, water resource allocation, and risk assessment (Di Lascio et al. 2002; Kucukmehmetoglu et al. 2010; Lee 1996; Lohani et al. 2006, 2012; Lu and Lo 2002; Lu et al. 1999; Mitra et al. 2002; Rai et al. 2014, 2017c; Sadiq et al. 2004; Saffiotti 1997). Fuzzy approach finds greater appeal among all sections including engineers, regulators, decision makers, policy makers, managers, expert panels, and other stakeholders. Politics is a major component of water management in transboundary rivers. The hydropolitics surrounding international rivers significantly affects the outcomes of negotiation and decision making by riparians in situations of conflict and cooperation. The political decision-making process involves linguistic data, which are vague and imprecise, and hence, a fuzzy inference system (FIS) finds its utility in transboundary water management. FIS introduces a soft dimension due to the inclusion of qualitative (linguistic) data.

Water resources management decisions are not an outcome of measured data only, because politics provide a dynamic process, which can easily change over time and cannot be measured crisply but involves immeasurable uncertain and fuzzy aspects. Fuzzy logic (FL) algorithm is also a powerful technique for modeling the nonlinear, uncertain, and complex systems with numerical and linguistic data in the form of an expert system (Özger and Şen 2007; Şen 2004, 2009; Simonovic 2012). By providing a systematic framework for computing with fuzzy logic greatly amplifies the power of human reasoning (Zadeh 1968).

This paper throws light on the range issues discussed in transboundary water management for international rivers. The issues considered here are in coherence with the list of issues discussed in the Basins At Risk (BAR) analysis carried out at Oregon State University. The highlight of this paper is the prioritization of the issues involved in transboundary river water sharing using FCM clustering algorithm. The FCM methodology is an up gradation over the hard clustering technique. Hard clustering partitions data into discrete clusters where each data element belongs exactly to one cluster. The objective of prioritization of issues in the present study is carried out by a novel approach FCM clustering. The data elements of fuzzy clusters can have different membership grades corresponding to different clusters (Jones 2012). The paper is divided into two sections: The first deals with how the issues which affect transboundary water sharing have been derived from the literature, while the other prioritizes the identified issues. The issues derived from the literature are cross-checked with the study carried out at Oregon State University under the BAR analysis of water events across the world. This has been carried out to check the relevance of the transboundary issues addressed here. The prioritization of issues would help in the identification of issues of high relevance which can facilitate smooth and efficient water compacts between riparians.

Water conflict and conflicting issues

A river is a naturally gifted treasure. It is essential to figure out the issues that affect the river for successful river management (Tiwari and Sharma 2014). The laws of nature and humans both prescribe that the ambient water resource must be shared by its dependents (Dellapenna 2007). The study conducted at the University of Alabama which studied 145 treaties dating from as early as 1870 which deal with water per se, and excluding those which deal only with boundaries, navigation, or fishing rights revealed interesting trends about international water treaties.

Most treaties focus on hydropower and water supplies: Fifty-seven (39%) treaties discuss hydroelectric generation, nine (6%) mention industrial uses, six (4%) mention navigation, six (4%) primarily discuss pollution, while thirteen (9%) focus on flood control. Seventy-eight (54%) treaties have monitoring provisions (which includes data sharing, surveying, and schedules for collecting data). Fifty-four (37%) have clearly defined allocations (Hamner and Wolf 1998). International water agreements or treaties still do not govern more than one third of the 263 international catchments with only some 30 having truly cooperative institutional agreements (Draper 2002, 2006, 2012b). Allocation of the scarce water resource to meet the various demands is considered the core issue in water management (Draper 2012b). Here the authors bring out the issues which hold relevance when transboundary water sharing is discussed between riparians.

Various scholars (Association 2004; Bakker 2007, 2009; Dellapenna 2007; Draper 1997, 2007; Gerlak et al. 2011; Hamner and Wolf 1998; Lowi 1995; Pahl-Wostl et al. 2008; Phelps 2007; Qaddumi 2008; Wolf 1997, 1998, 1999a; Zeitoun and Warner 2006) have discussed and reported the different parameters which influence water sharing in some form or the other. For water conflict resolution, one needs to have knowledge of all the issues that are responsible for it. There is no complete literature available regarding the issues which impact transboundary water sharing. The available literature has discussed the issues at times but in bits very often ignoring factors with little significance or external factors.

Here the issues include the direct as well as indirect aspects related to transboundary water interactions. The direct ones are those which are in direct connection to the water or its management, while the indirect ones are those which deal with external factors affecting transboundary water interaction, the negotiation process, and lastly the decision-making process. This is to include the more recent advances in transboundary management which advocates shifting away from sharing the physical water and move toward a more comprehensive view of benefits and its sharing (Rai and Sharma 2016). To formulate the list of relevant transboundary issues, the available literature was searched with the certain keywords concerning international water resources sharing.

The search database included keywords: irrigation, lake, river, canal, pollution, dam, hydro, water, barrage, reservoir, river, navigation, water resources, hydropower, hydroelectricity, stream, tributary, diversion, water quality, flood, drought, channel, relations, development, dispute, conflict, war, accord, negotiation, treaty, cooperation, hostility, treaty, agree, negotiate, resolution, commission, secretariat, joint management, basin management, peace, accord or "peace accord," settle, collaboration, disagree, sanction, water quantity, water sharing, data, or "data sharing," data exchange, flow, hydrohegemony, hydropolitics, environmental flow, ecology, EFR, cost, benefit–cost, water economics, benefit, sharing, or "benefit sharing," religion, culture, social, hydraulic, infrastructure, or "hydraulic infrastructure," riparian, bilateral, multilateral, international water law, water convention, water sharing principles, convention on the law of the non-navigational uses, Helsinki rules, water law, water policy, fishing, water boundary, river island, river boundary.

The search database helped in formulating the list of issues. These keywords have been used more often in the literature contributing to transboundary water management. Table 1 shows the supporting literature from which the corresponding issue has been derived out which affects transboundary water sharing. The literature cited in the table is not absolute, but they are just an indication that the issue has been discussed and debated around the world. There are many more studies which could be cited, and only a few have been cited here to support the basis of selection of the issue. It should not be considered that the cited literature is absolute.

In the Basins at Risk (BAR) analysis carried out at the Oregon State University, a list of issues was formulated to study the water events across the world. The list formulated in the present study is a step forward and superior keeping in view of the latest developments. It includes the issues highlighted in the BAR analysis and also adds a few external issues. The ones which are in accordance with BAR analysis are: water quantity, water quality, navigation, flood control, hydraulic infrastructure (includes irrigation, hydropower and infrastructure/development issues of BAR), conflicting internal law and policies (incorporates fishing, border issues, territorial issues of BAR), benefit sharing (includes economic development, joint management, technical cooperation/assistance of BAR). The additional issues are data sharing, hydrohegemony, environment flow and ecology, cost economics, religious, cultural and social issues, number of riparians involved, no ratified international law.

The issues of cost economics and benefit sharing though seem very similar as both deal with monetary aspects but are fundamentally different. Cost economics deals with how to arrange for funds for any water management or infrastructure project. Many nations are incapable of bearing the financial burden of water resource projects. It may happen in many basins which are governed by underdeveloped and developing countries and may not be affected by physical water scarcity, but they may certainly be gripped by economic water scarcity. This means that these basins lack the financial resources to use water at its merits. In such cases, these countries need to arrange for funding from international agencies like the World Bank or the Asian Development Bank. While benefit sharing deals with the economics of the projects after they have been completed and are ready to yields benefits, then the issue of benefit sharing comes into picture. Thus, it is clear that how cost economics is different from benefit sharing as far as water resources are considered. An example of cost economics is the Indus Water Treaty where the World Bank along with the government of Australia, Canada, West Germany, New Zealand, the USA, and the UK contributed largely in developing the water resources in India and Pakistan.

Resolution of water conflicts is all the more difficult with the nonexistence of single set of water law and policy or adequate legal conflict resolution forum. Information and data sharing engender good will and enhance confidence building among riparian states. Another important concern is that most of the international basins are multilateral, but most of the treaties are bilateral. With the effect of climate change being more pronounced, extremes of temperatures and rainfall can be experienced more often. This may lead to devastating floods which knows no political boundaries. Not just in the basins not governed by any treaty, but an in-depth analysis of the present water treaties will certainly reflect all the above issues in some way or the other either intrinsically or extrinsically. Table 1 shows the international basins affected by the various issues.

Table 1 Issues affecting international basins supported by the literature

Issue	Supporting literature	Affected basin
Water quantity and flow timings	Dellapenna (2007), Draper (2012b), Eheart (2002), Phelps (2007)	All international basins [Ex. GBM Basin (Indo-Bangladesh)]
Data sharing	Draper (2007), Gleditsch et al. (2006), Sneddon and Fox (2006), Toset et al. (2000), Wolf (1999c)	All international basins [Ex. Brahmaputra Basin (China–India)]
Water quality	(Bennett (2000), Boos-Hersberger (1997), Jacobs (2002), Shmueli (1999), Sigman (2001)	All well-developed international basins [Ex. Danube Basin, Ganges Basin (Indo-Bangladesh)]
Hydro hegemony and political influence	Warner (2004), Warner and Zeitoun (2008), Waterbury (2002), Zeitoun et al. (2010), Zeitoun and Warner (2006)	All international basins [Ex. Mekong Basin (Thailand–Cambodia–Laos–Vietnam)]
Environment flow and Ecology	Burchi (2012), Davis (2007), Jacobs (2002), Kallioras et al. (2006), Kistin and Ashton (2008), Richter (2010)	All international basins (Ex. Danube Basin)
Cost economics	Davis (2007), Lee and Floris (2003), Winpenny and Camdessus (2003)	All international basins which involves underdeveloped and developing nations [Ex. Indus Basin (Indo-Pak)]
Benefit sharing	(Dombrowsky (2009), Nicol et al. (2001), Phillips et al. (2006), Sadoff and Grey (2002, 2005), Turton (2008)	All international basins [Ex. Columbia Basin (the USA–Canada)]
Religious, cultural and social issues	van Binsbergen (2003), Gleick (2003), Pahl-Wostl et al. (2008), Reuss (2002)	All international basins [Ex. Ganges Basin (Indo-Nepal)]
Hydraulic infrastructure	Dams (2000), Grey and Sadoff (2006, 2007), Zeitoun and Warner (2006)	International basins involving developing nations [Ex. Brahmaputra Basin (Indo-China)]
Navigation	Bernauer (1997), Wolf (1999b, 2001)	Few international basins mainly in Europe (Ex. Danube Basin)
Flood control	Bakker (2007, 2009), Rahaman and Varis (2005), Wolf (1998)	Large number of international basins (Ex. GBM Basin)
Number of riparians involved	(Hamner and Wolf 1998, Ma et al. 2007, Wolf 1999b)	All multilaterally shared river basins (Ex. Mekong Basin, Nile Basin)
No ratified international law	Dellapenna (1996), Dinar et al. (2007), Draper (2012a), Fischhendler (2004), Frey (1993), Wolf (1998, 2002)	All international basins [Ex. Brahmaputra Basin (China–India)]
Conflicting internal law and policies	Cummings et al. (2002), Dellapenna (2001), Draper (2004, 2012a), Grant (2003), Sanchez (1997), Şen (2013)	All international basins [Ex. Ganges Basin (Nepal–India)]

Prioritization of transboundary river water sharing issues

After the identification of the issues that affect transboundary water sharing through rigorous literature review, a study was undertaken to prioritize the issues according to their importance. Though each river basin is different from the others, the relative importance of the issues will help the riparians to resolve the issues in a scientific manner. A hypothetical river basin is considered which is assumed to be affected by all the 14 number of issues identified through studies. To prioritize the issues, a group of 30 experts was consulted. The experts include representatives from government officials, water resources engineers and practitioners, NGO's, journalists, economists, environmentalists, water users, and researchers. An attempt has been made to maintain a balance between the numbers of experts from various fields. Experts from all major and allied fields were consulted from the Indian region. Government officials and representatives include both central and state government employees. Water resources engineers include the on-field experts who directly have to deal with complex situations. Experts from NGO's included the very specific NOG's working in water resources conservation and management. Economists are the experts in the area of economics who have the best idea of cost–benefit, finances, etc. The environmentalists include experts working in the areas of environment conservation, ecology, marine life, aquaculture, etc. Researchers which also include academicians are the ones working extensively as well as intensively in water resources. They introduce new technologies, theories, frameworks, or approaches in the management process. Lawyers are the ones who deal with any legal issues that arise in the due course of negotiation, document preparation, drafting rules and guidelines, etc. Lastly, the water users are the end users of the water. A good blend of experts has been selected for this study to get proper results. The bifurcation of the number of experts from various disciplines is given in Table 2.

The experts were selected according to the knowledge and experience in their respective fields. The experts selected have sufficient working knowledge of water management. Some of the experts have working extensively in transboundary water management. The government representatives and officials consulted are involved in policy and decision making. All the experts consulted are from India. The experts gave their views under the clause of anonymity so the particular details of the experts have not been disclosed. The authors contacted them in person to discuss the issues in detail and take their views after thorough deliberation. The experts were to rank the issues according to the relative importance. The following questionnaire was given to the experts:

Questionnaire: Consider a hypothetical river basin that is transboundary in nature and is gripped with all the direct and indirect issues discussed above.

1. Prioritize the issues in the order of importance keeping in view the hypothetical river basin.

The order of priority should consider the following aspects:

- Which of the issues is more relevant with respect to joint management of water resources?
- Which of the issues cause hindrance or is used as a tool to stall the negotiation process in the path of transboundary water management?
- While negotiating among riparians which of the identified issues should be discussed first that would help better manage the basin as a whole.

The ranks provided by the experts corresponding to the transboundary river sharing issues are given in Table 3.

Table 2 Details of the consulted experts

Fields of expert	Number (count)
Government representatives and officials	4
Water resources engineers and experts	4
NGO's	4
Economists	4
Environmentalists	4
Researchers	4
Lawyers	4
Water users	2

After assembling the ranks, it was analyzed with FCM clustering algorithm to find out the priority order (rank) of the issues affecting transboundary rivers. FCM clustering methodology has been adopted.

Prioritization methodology: fuzzy c-means (FCM) clustering

Prioritization is to arrange, organize, or deal with in order of importance. As a principle, it means doing "first things first"; as a process, it means evaluating a group of items and ranking them in their order of importance or urgency. It is particularly important when management of transboundary water resources is involved with water wars in the horizon. When conflict management is involved, prioritization of issues is considered of high relevance. This helps to bring to focus the core issues which need to be addressed immediately in order to manage conflicting claims to the common resources.

A cluster is a set of elements which have similarities between them and dissimilarities with objects belonging to other clusters. Depending on the characteristics of the data and the intended purpose for clustering, different measures of similarity may be used to classify the data into various clusters. The similarity measure controls the manner in which clusters are fashioned. Here, in the present study, FCM clustering has been used for clustering the ranks given by experts. FCM methodology clusters the ranks of each parameter and gives the cluster center which represents the prioritized rank of the issue.

Fuzzy clustering is a class of algorithms used for the analysis of clusters (popularly known as FCM clustering) in which the allocation of data elements to clusters is not hard but fuzzy in the same sense as fuzzy logic (Rezankova and Husek 2012). Fuzzy cluster analysis is employed to partition a given set of data or objects into clusters which can be groups, subsets, and classes. In fuzzy clustering, the allocation of data elements to clusters is not "hard" but "fuzzy" which is referred to as soft clustering (Belli et al. 2007). This is due to the property of fuzzy clustering which allows data objects to belong to more than one cluster (soft). Each element is associated with the clusters with a set of membership levels (Shankar et al. 2013). The process is to assign membership degrees and then using the assigned memberships to reassign data objects to one or more clusters. The strength of the association between that data object and a particular cluster is represented by the membership levels. The partition should follow homogeneity within clusters and heterogeneity between clusters.

Fuzzy c-means clustering has been preferred over simple averaging of the ranks obtained from the experts. This is because FCM accommodates the fuzziness in the data

Table 3 Experts ranks for transboundary water sharing issues

Water quantity	Data sharing	Water quality	Hydro hegemony	Environment and ecology	Economics	Benefit sharing	Religious and social differences	Hydraulic infrastructure	Navigation	Flood control	No. of riparians	No ratified law	Conflicting law and policy
3	9	4	6	7	8	2	12	5	10	1	13	11	14
2	5	3	11	10	8	9	14	4	6	1	12	7	13
5	4	1	12	2	10	9	11	8	13	3	14	6	7
1	5	4	11	3	10	6	12	7	14	2	13	9	8
7	8	9	6	10	11	2	12	4	13	3	1	14	5
1	12	6	8	3	9	7	13	5	14	2	4	11	10
1	10	7	5	8	12	2	9	6	13	3	11	14	4
1	9	2	10	3	4	11	12	5	7	6	8	13	14
1	5	3	8	2	4	9	13	6	7	11	10	12	14
1	2	3	8	6	9	4	14	7	10	5	13	11	12
6	5	7	13	4	12	1	14	3	8	2	10	9	11
2	5	1	4	3	9	10	13	8	14	6	12	7	11
4	6	5	8	1	7	10	9	2	12	3	11	14	13
5	8	1	12	6	7	3	14	4	13	2	10	9	11
4	5	9	8	1	7	10	13	3	14	2	12	6	11
5	7	4	9	1	6	2	10	8	11	3	12	14	13
10	9	8	11	2	12	1	13	5	14	3	6	7	4
7	6	5	10	11	8	9	2	12	1	13	4	3	14
5	3	1	4	7	6	2	14	8	13	11	10	9	12
2	3	5	4	1	6	7	8	9	10	11	13	12	14
5	4	7	6	1	8	2	14	10	11	3	9	12	13
1	10	2	5	3	9	4	11	6	8	7	12	14	13
3	8	1	7	4	11	6	12	5	13	2	14	10	9
2	9	3	7	8	6	1	13	5	10	4	14	11	12
7	6	10	4	9	8	1	5	12	13	11	3	3	2
8	2	3	7	10	12	1	6	11	13	9	5	14	4
2	5	11	4	10	6	1	12	9	13	7	8	14	3
7	5	12	4	11	8	1	9	10	14	6	3	13	2
2	8	13	4	1	7	5	14	3	12	6	9	10	11
2	8	4	5	6	9	3	10	7	11	1	12	12	14

collected from the experts. Moreover, simple averaging can result in same prioritized rank for more than one issue which can be avoided using FCM which does fulfill the objective of prioritization of the issues which affect or influence transboundary water sharing. Since all the experts have different backgrounds, they all view the same problem in a different way. So simple averaging cannot be the procedure that can be employed in case of prioritization of issues as it cannot deal with the fuzziness caused due to the variety in experts. As the main objective is prioritization of the issues, the theory and mathematics of FCM have not been dealt in detail. The utility of FCM has been used in prioritizing in the present study.

Analysis

In the present study, fuzzy cluster analysis, i.e., the FCM algorithm, is not used to cluster the individual ranks of each parameter into groups, rather the intended purpose is to find the center of the cluster consisting of individual ranks provided by the experts for each of the parameters. This means that the data (ranks) are beforehand classified into groups in the form of ranks awarded to the each of the issues. Hence, a total of 14 clusters were formed for the corresponding 14 issues. Each column in Table 3 represents a cluster. The objective is to find the center of all the 14 clusters. For the intended purpose, the "findcluster" tool given in MATLAB is used.

MATLAB is the Language of Technical Computing. In 2004, MATLAB had around one million users across industry and academia. MATLAB users come from various backgrounds of engineering, science, and economics to analyze and design the systems and products transforming our world. MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and fourth-generation programming language. A proprietary programming language developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, Fortran, and Python. It is used for machine learning, signal processing, image processing, computer vision, communications, computational finance, control design, robotics, and much more.

The clustering tool in MATLAB has two variations, namely subtractive and FCM, in the "findcluster" tool. In the present study, the clustering is done with FCM methodology rather than subtractive methodology. The basic layout of clustering tool with FCM algorithm is shown in Fig. 1.

FCM clustering results

Every cluster represents the corresponding issue which affects transboundary water sharing, and the cluster center represents the prioritized rank of the issue. The final result as obtained from FCM clustering algorithm is given in Table 4.

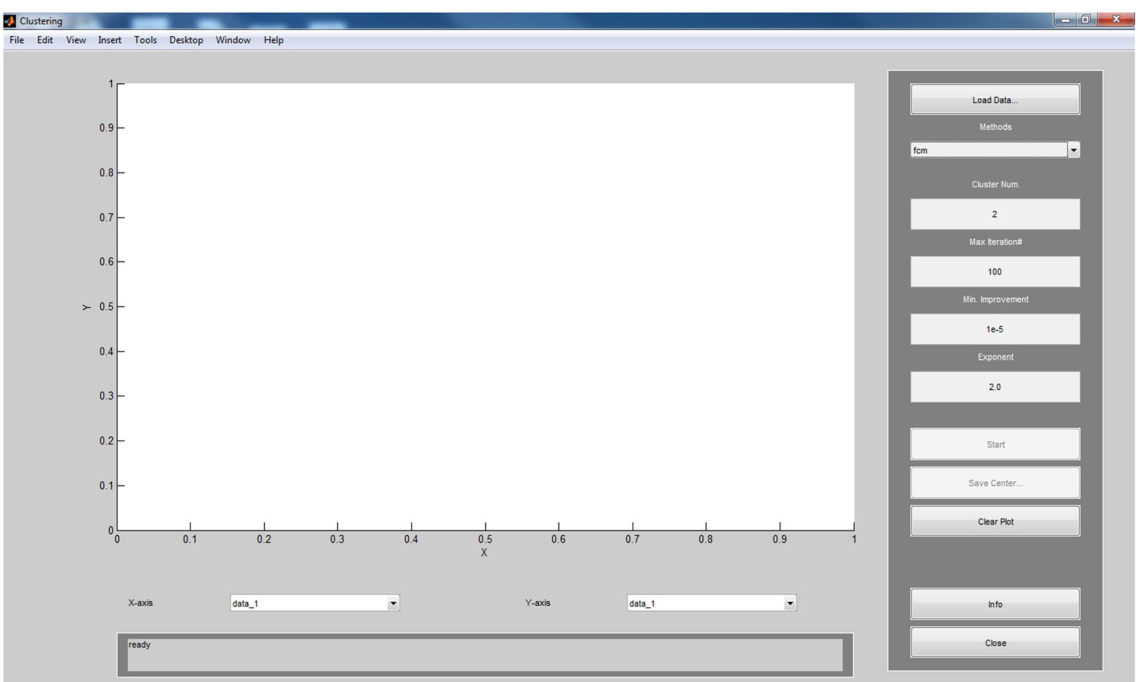

Fig. 1 Basic layout of clustering toolbox in MATLAB

The issues in Table 4 have been placed according to their prioritized ranks as obtained by FCM clustering algorithm. The results as obtained by FCM clustering have been compared with that of the simple average. There is a marked difference in the ranks obtained from FCM and simple average. As simple average does not consider the fuzziness, the results obtained from FCM have been further used in the study. For more clarity, the graphical result as obtained from FCM clustering is shown in Fig. 2 which highlights the clustering with the cluster center for the issue of water quantity and flow timings. Figure 2 depicts the typical clustering in two-dimensional feature space where *X*-axis and *Y*-axis represent the pairwise comparison of ranks obtained from the experts with respect to transboundary issues.

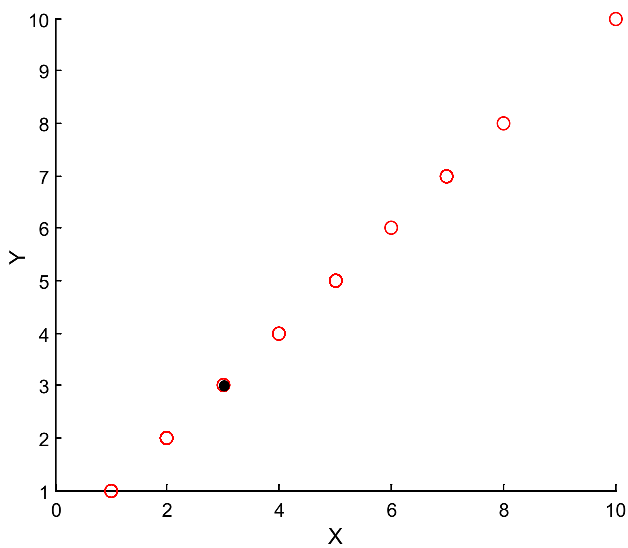

Fig. 2 Cluster of water quantity and flow timings parameter

The result derived from FCM clustering provides better insights to supplement transboundary water management. The issue of flood control has topped the table, and it rightly deserves the place. The result of the study conducted by Bakker (2007) which comprised of 1760 river floods that occurred during the period of 1985–2005, i.e., 21 years, reveals startling facts. These floods caused 112,000 casualties, affected around 354,370,000 people, and resulted in US$$6.87 \times 10^{11}$ fiscal dent. During this period, only 175 (only about one tenth) out of the total 1760 river flood events were transboundary, but they caused around 37,000 casualties, affected about 210×10^6 people, and resulted in more than US$$97 \times 10^9$ fiscal dent which constitute a significant number, greater than 10% in terms of the total number of deaths, affected people, and fiscal dent caused by the total number of river floods (Bakker 2007). The world needs to come together to reduce the effect of transboundary floods as it is devastating in every term be it causalities, people affected or economically.

Then, next is benefit sharing as the second priority. Until and unless there is equitable sharing of benefits, most countries defer joining any kind of treaty. The reason for it is that water is now no more a social asset only, and it is now considered as a socioeconomic asset. Water adds to the economic resources of the nations. Economic benefits are the driving force behind the water sharing. In many cases, the benefits are loaded in favor of the more powerful. Equitable and just benefit sharing mechanisms need to be developed in the right spirit so that all nations come forward for joint cooperation. In the times to come, with the commercialization of water, benefit sharing will certainly provide the

Table 4 Prioritized rank of transboundary issues

Issues	Prioritized rank from FCM	Prioritized rank from simple average
Flood control	1	3.7
Benefit sharing	2	6.4
Water quantity and flow timings	3	5.1
Water quality	4	7.4
Hydraulic infrastructure	5	5.1
Hydro hegemony and political influence	6	8.3
Environment and ecology	7	4.7
Economics	8	11.3
Data sharing	9	6.6
Navigation	10	11.2
No ratified international law	11	5.0
Religious and cultural differences and social issues	12	9.6
Number of riparians involved	13	10.4
Conflicting internal law and policies of riparian	14	9.9

strong driving force that will bring together hostile riparians to work together.

Benefit sharing is followed by issues pertaining to water quantity which is further followed by water quality. Number of riparians involved and conflicting internal law and policies are issues of low priority. One very important feature which is revealed from the study is that the absence of ratified international law is not ranked high on priorities chart. This means that had there been ratified international law, the scenario might not have been very different from what it is right now. The issue of hegemony has been prioritized quite high. This reveals that there is growing realization about how the hegemony of the riparians influences the final outcome in water sharing process. Even till date navigation has not lost its shine completely and still finds relevance in numerous river systems.

Conclusion

1. Allocation of the water resources to meet the various demands which is considered to be the core issue (Draper 2012b) may not necessarily be the issues of prime importance in all river basins.
2. Though all river basins do not have similar characteristics, the prioritization algorithm suggested through this study using hypothetical river basin affected by all the issues can be used to study and analyze in detail the international river basins of the world.
3. The methodology as suggested by the authors in this paper can be used in transboundary water management in order to bring to fore the prime issues concerning particular basins.
4. At first, it is suggested to know the issues which affect particular basin; then, FCM clustering algorithm can be used as a methodological tool to carry out the preliminary analysis of shared basins.
5. The application of the FCM approach in management of international river basins is the highlight of the study. The approach may be useful in transboundary water management and understanding international water conflicts. This approach should help in more informed decision making by various governments, intergovernmental agencies, etc.

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Authors' contributions Dr. Subash Prasad Rai made substantial contributions to conception and design, carried out the analysis, and drafted the manuscript. Prof. Nayan Sharma made substantial contributions to conception and design and helped in interpretation of results. Dr. Anil Kumar Lohani made substantial contributions to conception and design and was involved in drafting the manuscript.

Compliance with ethical standards

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