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Multicriteria Decision Analysis for Flood Risk Management: The Case of the Mapai Dam at the Limpopo River Basin, Mozambique

Avelino I. Mondlane

Abstract

In this article, we present evaluations of the different scenarios for building the Mapai Dam in the Limpopo River Basin of Mozambique as an integral part of the flood risk management in the basin. The study used various decision analysis software packages such as V.I.S.A and Decide IT, which are basically instances of decision support systems. In order to perform the evaluation, we used sources available to assess the need and feasibility to build the Dam, which provides the basis for our analysis. We first structured the problem in order to make it more understandable through a value measurement tree, then built a decision making tree to develop different scenarios, whereby we compared their outputs based on a probabilistic analysis, according to their storage capacities. The results prove that the system is helpful in decision-making process, particularly when we face multiple choices.

Keywords: decision support system, flood risk management, Mapai Dam, multicriteria decision making

1. Introduction

Mozambique is one of the least developed countries in the Southern African development community (SADC) region with 2700 km of coastline [1]. The country is already experiencing the devastating effects of droughts, floods, and cyclones on agricultural production such as crops, livestock, forest, and fisheries both in rural and in coastal areas from climate change [2]. This is true in particular with respect to some shared international basins with hinterland countries [3], and moreover within the Limpopo River Basin as a result of the extreme

weather and the lack of flood control mechanisms. With an area of about 400,000 km², the Limpopo Basin occupies between 11 and 16% of the area of the four riparian countries, namely Botswana, Mozambique, South Africa, and Zimbabwe, and the river flows into the Indian Ocean at Mozambique Channel [4] (**Figure 1**). The population of the basin is approximately 14 million, of which half is in Botswana and less than 10% is in Mozambique and Zimbabwe [5].

Together with its tributaries, the Limpopo River is expected to be significantly affected by the climate change [6] and as a consequence there is an urgent need to address the high vulnerability of the population within the basin. The government of Mozambique identified the District of Chicualacuala to start the United Nations joint programme (UNJP) on Environmental Mainstreaming and Adaptation to Climate Change for the period between 2008 and 2011 with a total of USD 7 million funding [7]. According to Ref. [8], climate change is expected to affect the precipitation, potential evaporation, and runoff in Limpopo Basin, which may bring changes in water supply, leading to power shortages due to the reduced rainfall.

In 2000, floods devastated Mozambique with the cost estimated at 20% of the gross domestic product (GDP), slowed down the yearly economic growth to 2% [9]. The development of Mapai Dam is one of the strategies identified by the government of Mozambique to minimize the impact of floods in the Limpopo River Basin, since Mozambique is the only country in the basin with limited capacity of water storage among the riparian countries as indicated in **Figure 1**. The statistical data from [4] show that Mozambique has only one dam with a large storage capacity, which is the Massingir Dam in the Elephants River with around 2800 Mm³
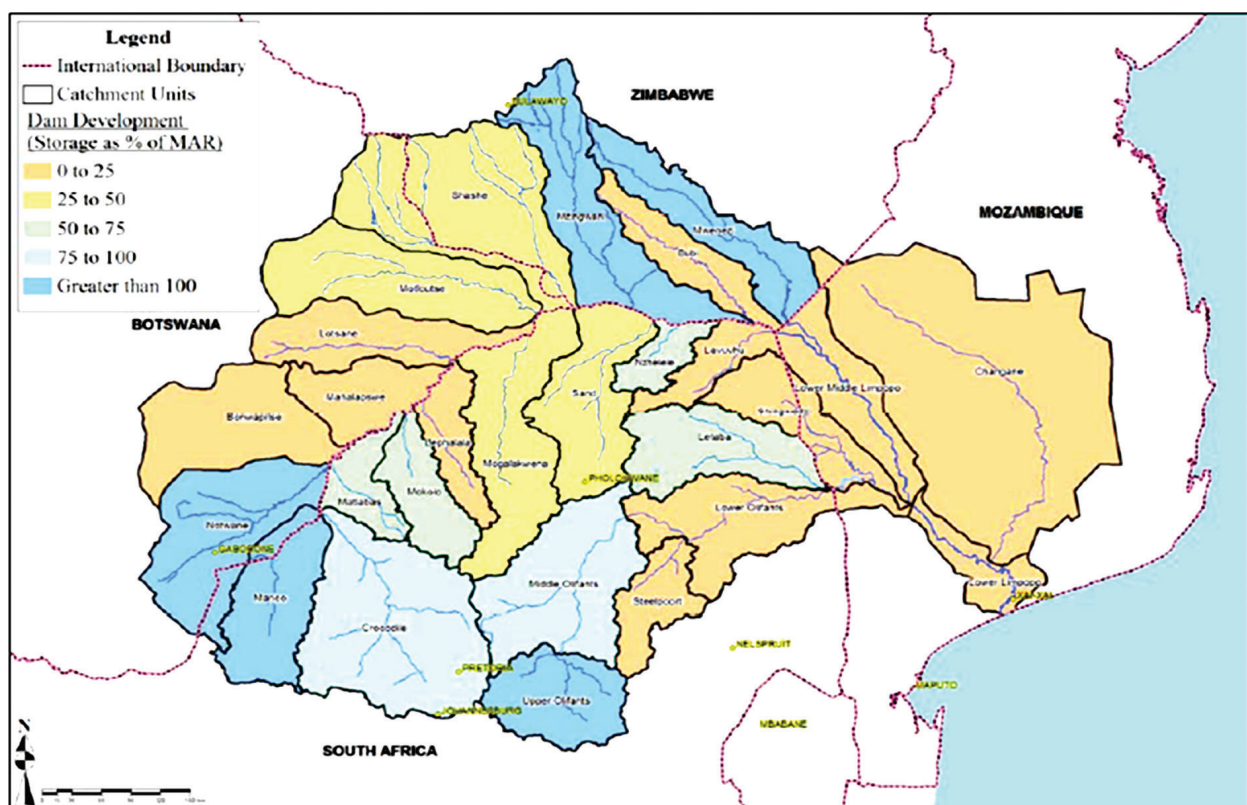

Figure 1. Distribution of water demand (as % of mean annual runoff (MAR)) for sub catchments of the Limpopo River Basin. *Source:* Ref. [11].

of capacity. However, this dam operates below its capacity after going through a technical accident in the 1980s. An additional infrastructure is the Macarretane Dam on the Limpopo River in Chókwe with approximately 4 Mm^3 storage capacity. Botswana has four large dams and plans to build additional three in the near future, while South Africa has a quite large number of dams, with 160 classified as large storage. In Zimbabwe, there are 12 dams ranging from medium to large capacity [10]. The limitation of water storage in the Mozambican section worsens the impact of floods, which has negative economic, social, and environmental implications. Herein, we analyze the different scenarios and impact of this structural coping mechanism.

Limpopo River is of vital importance for the country not only for economic and social systems but also for the functioning of natural ecosystems. An illustrative example is Chókwe District in the downstream area with strong potential for agriculture based on the irrigation system, which is called the granary of the nation, due to the irrigated agricultural practice.

According to Ref. [12], the Master Plan for Prevention and Mitigation of Natural Disasters established in March 2006 by the Government of Mozambique (GoM) outlined the emergency procedures for government agencies, the structure and organization of the national emergency operations center, and its regional branches. The Master Plan also highlights disaster preparedness as an essential part of government concerns to be included in the poverty reduction strategy (PARPA) as a crosscutting agenda. The set of actions includes the flood early warning system, introduction of drought-resistant crops, and the information and communication management systems for national emergencies. PARPA constitutes one of the guidelines for the water resources assistance strategies in the country [2].

One of the objectives of this article is to develop simultaneously an analytical procedure using multicriteria decision analysis (MCDA) in order to accommodate different and conflicting objectives by the involved stakeholders based on a decision support system (DSS) as a part of an MCDA process. Initially, we structure the problem, using value three measurements, using V.I.S.A,[1] aiming to make the problems more understandable. Lastly, we use Decide IT,[2] a decision-making support system to develop a decision tree to structure the problem and develop our analysis.

The outline of this article is as follows: the introduction (present section) gives the background information about Mozambique and the formulation of the problem. The second section summarizes the applied methodology, which is followed by the main water resources strategies for the country. The main steps and the key concepts related to MCDA and multicriteria decision making (MCDM) are presented in Section 3, while in Section 4, we structure the problem and present the basic assumptions toward scenario building in decision making. Section 5 brings the solution to the study problem, by applying a DSS based

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[1]V·I·S·A stands for Visual Interactive Sensitivity Analysis. It is a software for decisions with multiple, tough to balance, factors; for decisions where no option matches all of the criteria perfectly; or for decisions where more than one person has a say in how the decision is made. It does not tell you the "right answer," it lets everyone involved see for themselves what the best overall decision is, weighing up all the factors using a considered and sound process. (http://www.visadecisions.com/visa_more.php.)
[2]Decide IT is among the software used at the Department of Computer and Systems Science, developed by Preference-Consulting Developer of Software for Risk and Decision Analysis (http://www.preference.bz).

on Decide IT software, where we developed all possible outputs, provided the decision and willingness of the stakeholders to abide by the decision. We provided the analysis in Section 6 along with the discussion of the results, and finally in Section 7, we present the conclusions and future work.

2. Methodology and materials

Flood risk management as a multidisciplinary activity is subjected to different and multiple choices in a conflicting situation for the involved stakeholders. In Mozambique, flood risk management is under the responsibilities of National Institute for disaster management (INGC), but different stakeholders are actively involved in the process. Among these are the Mozambique Red Cross, the National Institute of Meteorology, United Nations agencies, and the National Defense Forces.

The authors [13] address sensitive analysis as one of the decisive steps in building models, and by adopting such concept, we evaluate different options for the development of Mapai Dam, taking into consideration different scenarios based on storage capacities, bearing in mind two different perspectives: the *de facto* situation and alternative(s) for building the Dam with a specific and optional storage capacity.

Our study was based on a field survey and analysis of documents in order to get insight on whether to build or not the Mapai Dam. Moreover, a fieldwork was performed in Chókwe District between 8 and 22 April 2013 aiming to assess the impact of floods in the basin and evaluate to what extent the Mapai Dam could influence the management of the basin. About 90% of the interviewees indicated that there is a strong need to develop the Mapai Dam in order to minimize the impact of floods and also to bring better control on water management for agriculture.

The data collected during the fieldwork were aggregated for different probabilities according to responses of the interviewees. Furthermore, the probabilities are incorporated into a chosen decision support system, the Decide IT, which is part of the tools used for our research.

We used the DSS module of Decide IT to build a decision tree for scenario analysis. This can be linked to multiple purpose analysis, given the different options that are generated, hence is linked to MCDA. The literature survey of different sources of information among governmental documents in regard to strategies for flood risk management over Limpopo River Basin also shows to what extent there is need of an effective infrastructure mechanism, see **Table 1**. The Mapai Dam is also listed in the AQUASTAT database for irrigation with a capacity of 11.2 Mm^3 [14], as part of major African basin infrastructures.

Table 1 shows the selection and sources of the material used, which stress the need for the development of the Mapai Dam in the Limpopo River Basin in order to minimize the impact of floods downstream. The World Bank has shown some commitment to support the water resources strategies in Mozambique. In 2007, the organization developed the country's water resources assistance strategy, which congregates different approaches and strategies already in use in Mozambique and includes the inputs from consultations with the government, the

Title	Year	Source	Type of document
Strategic plan for the development of Gaza Province	2007	[15]	Strategic plan
Mozambique Country water resources assistance strategy: Making water work for sustainable growth and poverty reduction	2007	[16]	Technical consulting document
Limpopo Basin permanent technical committee – LBPTC Joint Limpopo River Basin Study Scoping Phase	2010	[4]	Technical report
Centro de Promoção De Investimentos CPI	2012	[17]	Advocacy for investment
Profile of the Limpopo Basin in Mozambique, a contribution to the challenge program on water and food project 17 livelihoods: Managing risk, mitigating drought and improving water productivity in the water scarce Limpopo Basin"	2009	[18]	Research project
FCEC-CPLP. Fórum Para a Cooperação Económica E Comercial Entre a China E Os Países de Língua Portuguesa	2012	[19]	International forum advocating investment
Water-use accounts in CPWF basins: Simple water-use accounting of Limpopo Basin	2010	[14]	Working paper, basin focal project series
Sustainable land use planning for integrated land and water management for disaster preparedness and vulnerability reduction in the Limpopo Basin	2007	[20]	Limpopo Basin strategic plan
Mozambique: Government looking for funding for Mapai Dam	2013	[21]	State House news
Republic of Mozambique: Poverty reduction strategy paper—economic and social plan for 2005	2005	[22]	IMF country report (No. 05/312)
Official development assistance to Mozambique Database: Project fact sheet for 8 ACP MOZ 024-19	2005	[23]	Project fact sheet for 8 ACP MOZ 024-19
Limpopo River awareness kit	2014	[24]	Official home page

Table 1. List of main references of Mapai Dam through various studies.

stakeholders, and the donors as shown in **Figure 2**. Here the Mapai Dam project development is addressed as a part of the strategies for the main water sectors.

In Mozambique and the Limpopo River Basin, there is a need to establish agreements to share water resources with the neighbors and build the Mapai Dam on the Limpopo River for irrigation purposes, flood control, control of saltwater intrusion, and ensure minimum flows for ecological reasons. Based on Ref. [18], there is also a need to promote the development of small dams for water supply for livestock and the rural population. According to the National Directorate of Water in Mozambique [18], the main source of water supply in urban centers in the Mozambique Limpopo Basin (Chókwe and Xai-Xai) is ground water, whose characteristics are covered by **Figure 2**. It seems that the agriculture sector has increased the use of surface water in the basin. The potential irrigable area of the Limpopo River basin in the Mozambican territory is estimated around 148,000 ha, of which about 50% is equipped with irrigation infrastructure and 27% is operational [18].

The development of Mapai Dam fits within the country's water resources assistance strategy, and it will bring changes in different sectors such as irrigation, urban and rural water supply,
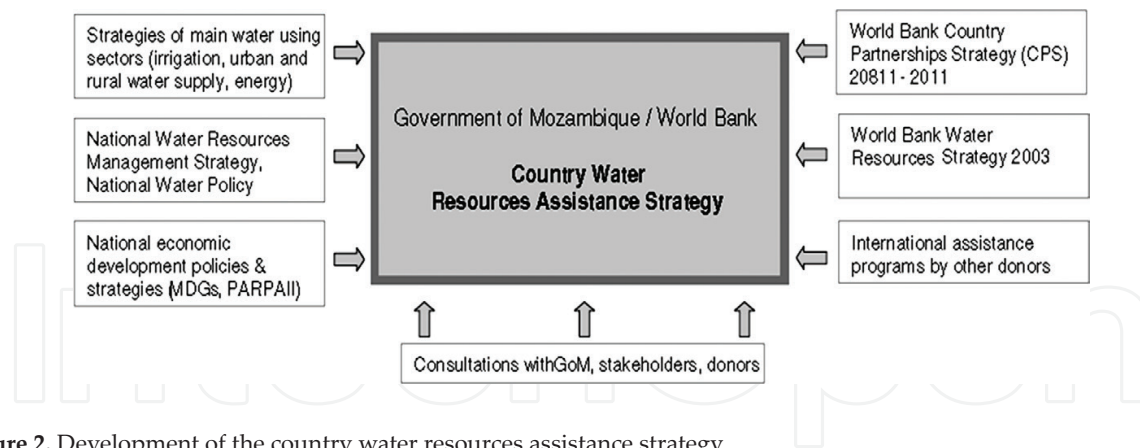
Figure 2. Development of the country water resources assistance strategy.

and energy, as well as to reinforce the national water resources and national economic developments. To meet these challenges Mozambique counts on cooperation of international partnership such as with the World Bank and other international assistance as shown in **Figure 2**.

The development of the Mapai Dam in the Limpopo River Basin is of interest to many of the interviewed parties such as the water management authority of the local government, farmers, other water management institutions such as administração regional de aguas do sul (ARA Sul) and national water administration (ANE), the Government of Gaza, the Center for Promotion of Investment, the INGC, the National Institute of Meteorology, the UN agencies, and the Mozambique Red Cross. It is clear that in many ways the stakeholders play a decisive role for the development of the Mapai Dam.

3. MCDA/(M) methods

According to Ref. [5] by the 1970s, the research on MCDM focused on the theoretical foundations of multiple mathematical programming procedures and algorithms for solving multiple objective mathematical programming problems. The author [25] argues that in multicriteria analysis problems several criteria are simultaneously optimized in a feasible set of finite number of given choices. The author [26] defines multicriteria decision making (MCDM) as a collection of methods to compare, select, or rank multiple alternatives that typically involve incommensurate attributes. It is well suited for eliciting and modeling the flood preferences of stakeholders and for improving the coordination among the flood agencies, various organizations, and the affected citizens.

Multi-attribute methods follow two schools of thought: American/Anglo-Saxon and European/French. Multi-attribute utility or value theory (MAUT or MAVT) and the analytical hierarchy process (AHP) are the main methods used in the United States, while the French school developed the outranking methods of ELECTRE (*elimination et choix traduisant la realité*) and preference ranking organization method for enrichment of evaluations (PROMETHEE) that are dominant in Europe. In Ref. [27], one can find more details about the advantages and disadvantages of both approaches.

Decision support system architecture for flood modeling under consideration integrates the latest advances in MCDM, remote, GIS, hydrologic models, and real-time flood information systems. The author [28] defines a decision support system (DSS) as "a computer-based information system used to support decision-making activities in situations where it is not possible or desirable to have an automated system performing the entire decision process." Based on Ref. [5], by the 1980s, the emphasis within the MCDM, through the increased use of computers, shifted to DSS. Furthermore, they define the multicriteria decision support system (MCDSS) as simply a DSS that implements MCDM and/or MAUT/MAVT models.

The specific characteristics of MCDSS that, in a way, differentiate them from the ordinary DSS is that they include analysis of multiple criteria, involvement of MCDM methods, and the integration of the user in the input during the modeling process [5]. A DSS is customized, interactive computing environment that integrates model/analytical tools, databases, graphical user interfaces, and other systems. In addition, Levy [26] notes that DSSs are designed to help decision makers use data and models to evaluate unstructured problems that require the management judgment. A significant number of authors and their work with respect to DSS and MCDSS are extensively discussed in Ref. [26].

As in many hydrological hazards within flood risk management, the transformation of qualitative factors such as environmental quality, social impact, ecological concerns, and political issues into quantitative, financial, values constitute a significant drawback to cost-benefit analysis approach. Both qualitative and quantitative issues can be handled within the process of decision making through the MCDM because it provides a systematic procedure to the decision makers to identify desirable alternatives under uncertainty. According to Ref. [29], the process of decision making where multiple conflicting criteria are involved is classified into two main stages: (1) multiple objective problems, which have an infinite number of feasible alternatives and (2) multiple attribute problems, which have a finite set of feasible alternatives. Given the importance of this analysis for our research we performed an MCDA analytical process for the dam installation in the Mapai village.

4. Assumptions and problem structuring

Within the sector of water and sanitation, the Strategic Plan for the Development of Gaza Province [15] defines the construction of Mapai Dam as one of the top priorities. The main objective is to improve the territorial waters and to guarantee the flows of international rivers of the Limpopo River Basin. The Mapai Dam site is foreseen between Phafuri and Combomune [15] along the Limpopo River, and it has been identified as one of the most strategic location for the estimated USD 450 million cost dam [19].

The government of Mozambique (GoM) has been advocating among international partners and stakeholders for a fundraising process for the Mapai Dam. The Mozambique Investment Promotion Centre [17] is one of the national entities that have led the process. Recently, at the Forum for Economic and Trade Cooperation between China and Portuguese-Speaking Countries [19], the Mapai Dam was one of the top issues that put forward by the GoM.

According to Ref. [10], the earlier research done by the end of the 1960s showed that the main benefits derived from the development of Mapai Dam are:

(a) Availability of water for irrigation of about 40,000 ha at the low and medium part of Limpopo Valley;

(b) Power Center with a capacity to produce 40 MW electricity;

(c) Reduction of migration by providing job opportunities;

(d) Supply of drinking water to the population (presently, the inhabitants are drinking water from boreholes); and

(e) Flood protection for Xai-Xai and Chókwe at the Low Limpopo Valley in coordination with the Massingir Dam.

In the late 1970s, an additional hydrological study performed in regard to building the Mapai Dam showed a reservoir with an estimated 11,200 Mm^3 of water at retention level of 180 m above Mean Sea Level (MSL), or 6600 Mm^3 at 170 m above Mean Sea Level (MSL). In order to estimate the impact of the usage of these reservoirs, in the scope of flood control, a brief analysis was conducted by ANE in 2006. This analysis, as show in **Figure 3**, focused on the potential changes within Combomune hydrographic designs downstream.

The advantage of value tree measurement illustration is that it can reflect the outcome of the brainstorming sessions by the stakeholders with respect to the problem and concerning a specific order or a course of action. A study for ANE by Ref. [10] shows that for each size of the reservoir and a series of hydrographical analysis, the maximum optimum flow from the reservoir was calculated as the maximum flow that allows the reservoir to support its full
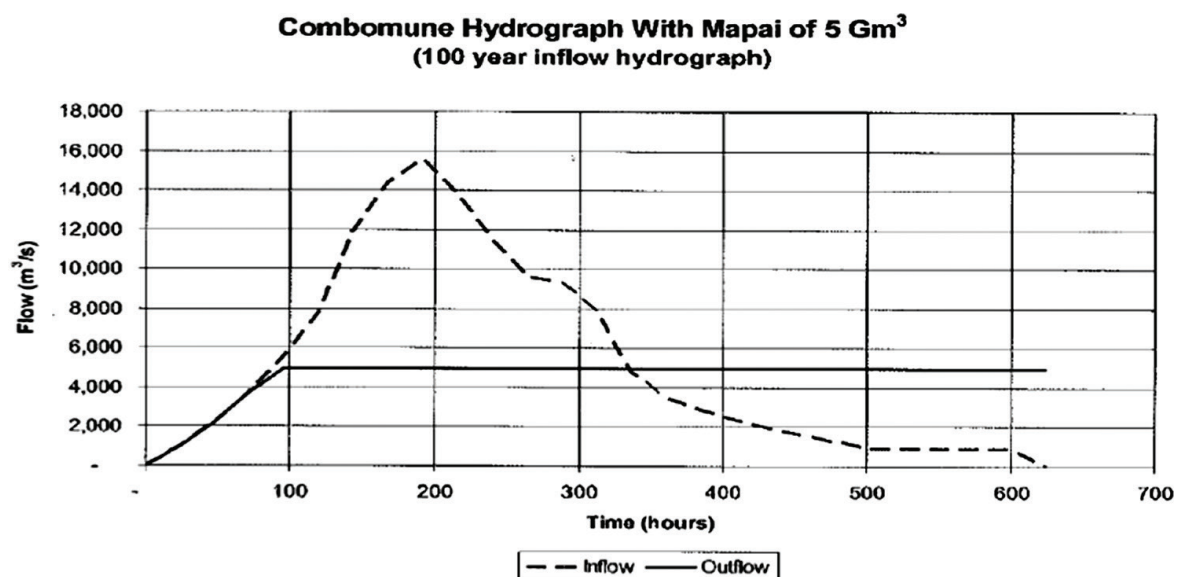

Figure 3. An example of hydrograph model with Mapai at Combomune. *Source:* Ref. [10].

capacity, while avoiding an over flow. The calculations, rather simple to perform, require just a perfect knowledge of hydrographic effluent. Being an ideal case, it is rather not applicable in reality. Nevertheless, it is a good guide for an achievable flood mitigation process when a reservoir is used.

To understand the complexity of this project we present in **Figure 4** an overview of the value tree measure, which provides better understanding of the project.

To demonstrate how different scenarios can be illustrated we used a value measurement tree, **Figure 4**, to structure the different possible outcomes. Based on their profiles, we can evaluate the behavior of different outputs in the score profile across the tree. Three potential "active-volumes" reservoirs used to control the floods were assumed as follows:

(a) 2000 Mm³, close to the capacity of a reservoir initially used for other purpose (for example supply of water for irrigation and hydropower) but with separate capacity for flood control;

(b) 5000 Mm³, close to the capacity of a reservoir initially used for flood control;

(c) 10,000 Mm³, close to a reservoir of larger capacity with a sophisticated system of forecasting and administration, in order to maximize the primary flood control function.

The value tree in **Figure 4** shows how different scenarios can be interpreted and helps to make a decision. Here, we can see how the optimal changes in the node of a dam with 10,000 m³ may bring positive impacts on health facilities, water supply, agriculture, and power supply.
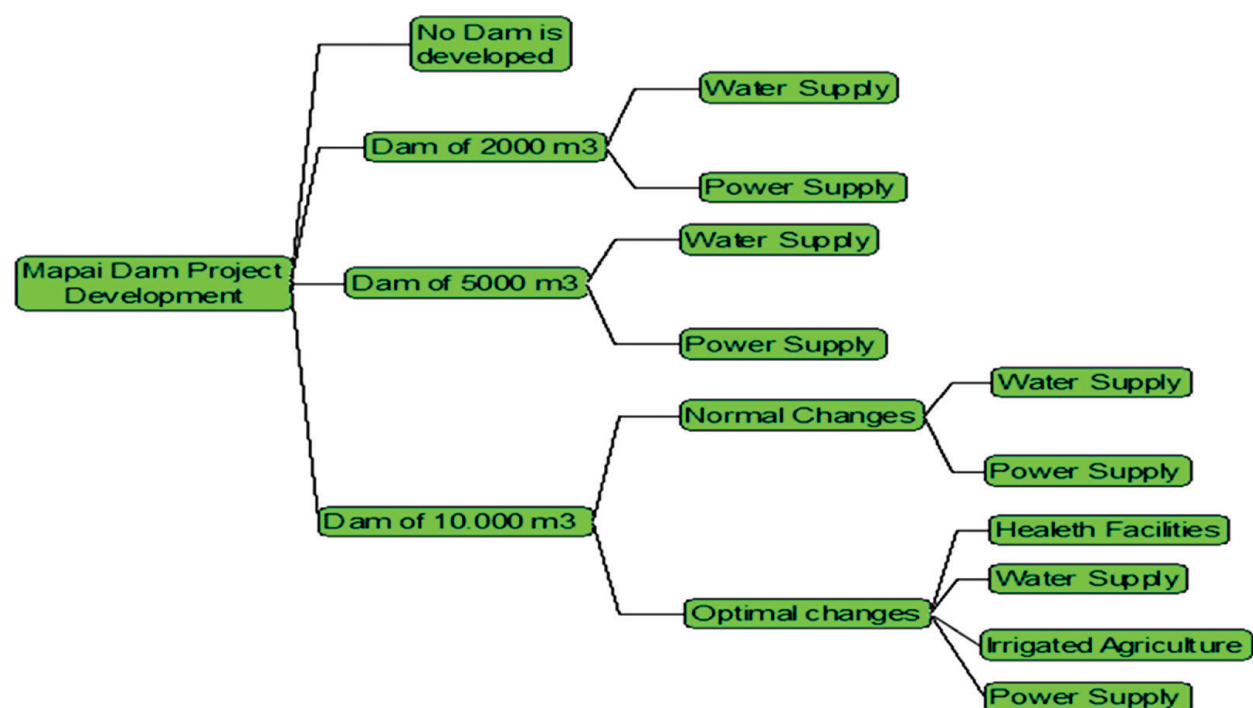

Figure 4. The value tree structure for the Mapai Dam project.

4.1. Decision making and scenario planning

As discussed before, the issue of the Mapai Dam is a strategic decision for the development of the water and sanitation system in Gaza Province [15] with a particular impact along the Limpopo River Basin. Prevailing the uncertainty on the topic, due to the absence of data that could be used for this particular research, going through academic exercise and in order to validate the application used, from the three scenarios defined in this research, we may generate the following assumptions. Initially, we assume the two alternatives of constructing or not constructing the dam, given possible different and conflicting stakeholder opinions, having equal probability of 50% each. Alternative one will be to construct the dam at the cost of USD 450 million according to Ref. [19], and alternative two will be not to construct the dam, meaning to continue with the current situation.

As a result of the fieldwork performed in Chókwe District between 8 and 22 April 2013, we selected several probabilistic indicators, which were used to simulate and analyze the data in a decision support system, or more specifically, to build an analytical decision tree in Decide IT (**Figure 5**).

This decision three is built based on the three main scenarios (**Figure 5**), where alternative one is branched at Nodes E1, E3, and E5, with probabilities $P = 0.4$, $P = 0.35$, and $P = 0.25$, respectively, for building dams with 2000, 5000, and 10,000 Mm^3 storage capacity [10]. Based on the literature (**Table 1**) and interviews with the stakeholders in Chókwe District, we summarize that:

(1) With alternative one, the following three outcomes are expected, based on the information in [31]:

    (a) The 40% probability of installation of a dam with 2000 Mm^3 storage capacity will bring basic changes to the living standard, with probabilities between 10 and 24% for water supply and between 16 and 30% for power supply (node E1);

    (a) The 35% probability of the installation of a dam with 5000 Mm^3 storage capacity will create medium changes to the living standard, with probabilities between 0 and 35% for both the water and the power supplies (node E3);

    (a) Lastly, the 25% probability for installation of a dam with 10,000 Mm^3 storage capacity should bring significant changes to the living standard, with probabilities between 10 and 30% for providing drinking water and irrigation facilities, power supply, and job creation (node D1).

(2) Node D1 in **Figure 5** illustrates the critical scenario for our research. Regrettably, this is not what happens with the node E4, which although provides all qualities given in D1, has limitations.

(3) The availability of water for irrigation of about 40,000 ha farmland at the low and middle part of the Limpopo Valley is to some extent expected to boost both the agriculture and the livestock production capabilities of the area.

(4) Power station with a capacity of 40 MW will increase the capacity of industrial production and the access to clean energy.

(5) Reduction of migration by creating job opportunities that will ensure the decline of un-employment rate and rise of social and economic development within the region with some positive impact on gender equality. Guarantee to supply potable water to the population, which will enable access to clean water and guarantee that school aged girls focus on their study requirements and daily responsibilities rather than spending time to fetch water for the families.

(6) Flood protection for Xai-Xai and Chókwe at the Low Limpopo Valley in coordination with the Massingir Dam. This will provide security to thousands of people and the economic assets that are highly exposed to floods risk along the basin, especially to the cities that are frequently flooded.

In the next section, we use two decision support software—Decide IT and V.I.S.A—to provide more analytical options based on the assumed probabilities for each scenario. The main motivation on choosing the Decide IT software is that flexibility that it offers on the analysis of different options based on a decision tree.

5. The application of DSS

The main purpose of using Decide IT is to accommodate the probabilities discussed in Section 4.1 in order to build the decision tree model for the Mapai Dam in Gaza Province, taking into account different proposals and priorities from various stakeholders.

The output of this process is shown in **Figure 5**, which illustrates the outcomes derived from discussions with the stakeholders interviewed during the fieldwork. This decision tree integrates
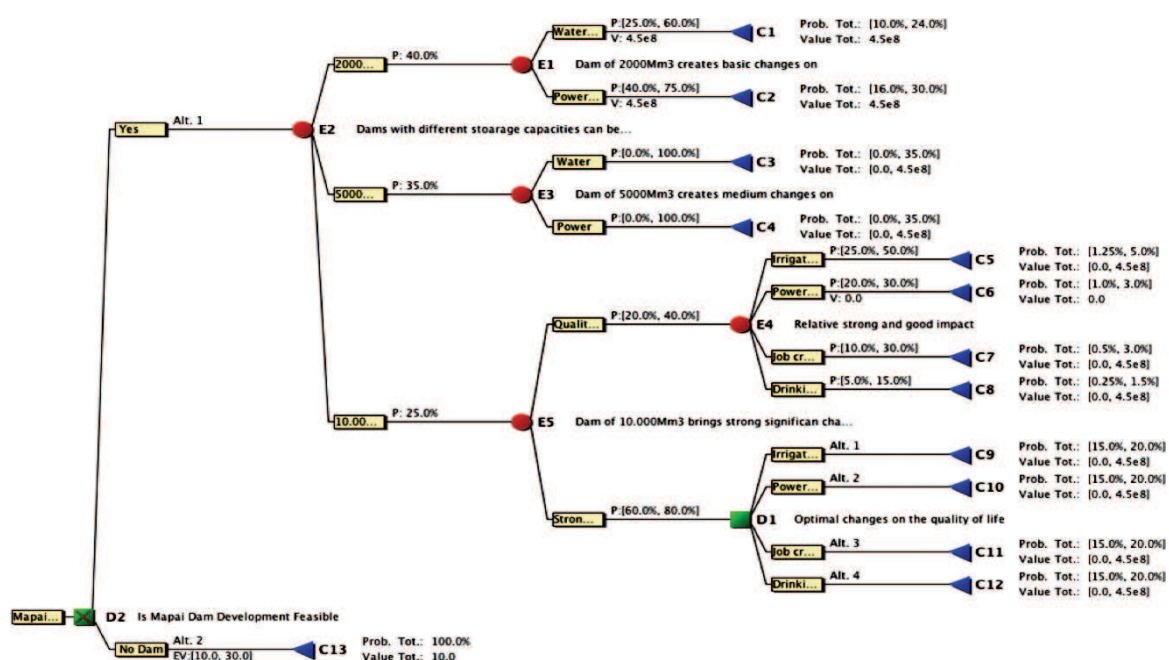

Figure 5. Decision making process for the Mapai Dam project.

multiple objective managements reflected in different scenarios. Hierarchical and network models are used to understand the relationships among multiple and competing objectives. Nodes E1, E2, and E5 represent different stakeholders' options and opinions.

Figure 5 depicts different outputs of stakeholders' options on possible conflicting objectives, which represent the scenarios derived from trade-offs and specific benefits that each variant of the dam may deliver. Modeling processes can also be built on V.I.S.A, another DSS extensively used to build MCDA scenarios, through comparative analysis of the behavior of score profile across tree from the present situation that ranges from not building a dam to the development of the optimal alternative of a dam with the maximum storage capacity, as shown in **Figure 6**.

Figure 6 illustrates the profile of different scenarios that stem from the installation of the dam with different storage capacities. The scale varies from worst, which is equivalent to zero improvement, to best that corresponds to 100 units. The actual or the current situation, where no dam is being built, shows zero units, while a dam of 2000 Mm^3 will provide power and water up to 50 units of the scale.

A dam of 5000 Mm^3 shows some improved results, while the last one even brings changes on agriculture and health, which are reflected in a well positioning of all dimensions, namely, economic, social, environmental, and coping mechanisms. Usually decision making is based on a cost-benefit analysis to determine the optimal alternative. We develop this analysis based on the impact of different dam alternatives or options (types and storage capacities), as shown in **Figure 7**, where we can see the effects that different storage capacities have on the economic, social, environmental, and particularly, health systems.

As shown in **Figures 6** and **7**, apart from the financial constraints, the construction of the Mapai Dam covers different areas of interest including, but not limited to, demography, water and sanitation, flood management, environmental issues, the risk of floods damage, and geology. Different types of real life problems in management practice can be formulated as a multicriteria
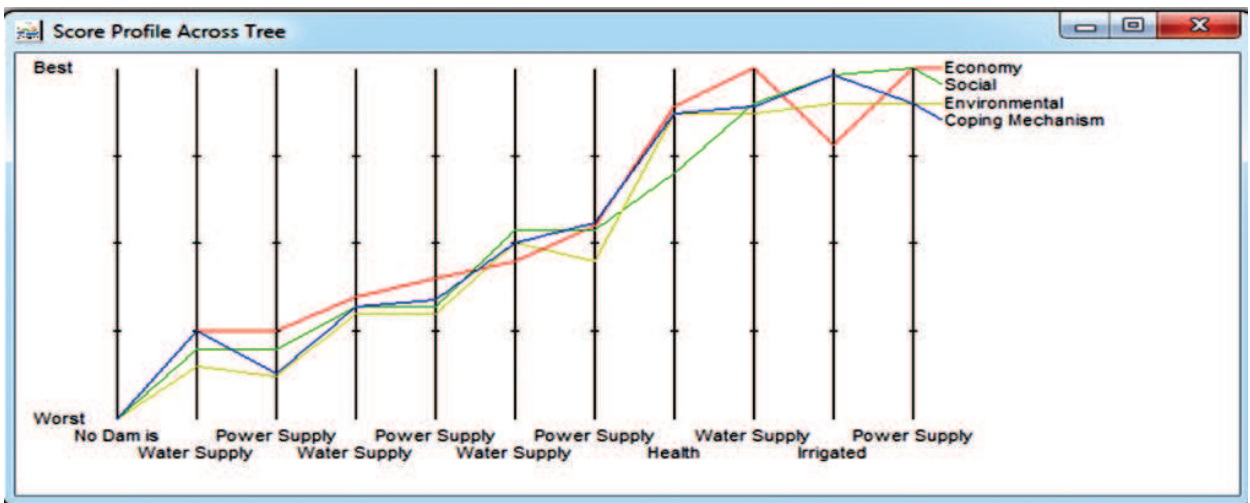

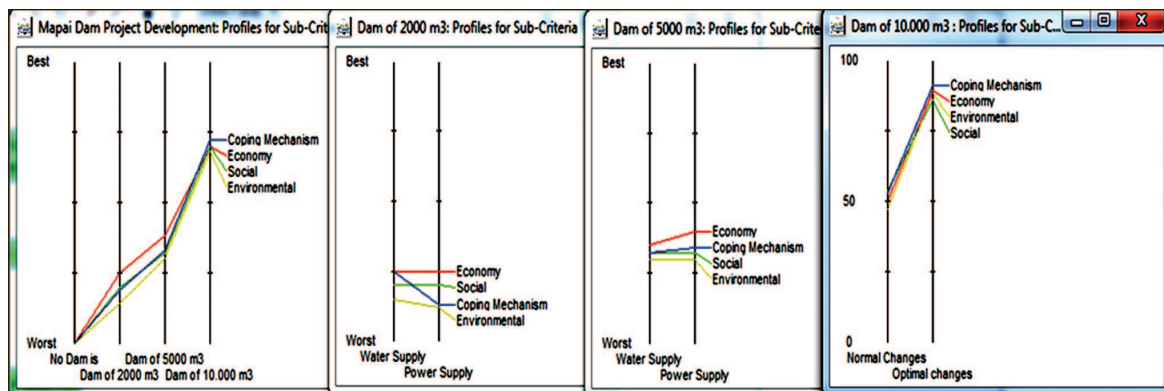**Figure 6.** Score profile behavior across Tree.

Figure 7. Profile of each sub-criterion according to the storage capacity.

analysis problem, when one has to involve the evaluation and choice of resources, strategies, offers, policies, products, innovations, designs, costs, profits, portfolios, and tools [25].

6. Findings and analysis

The development of the Mapai Dam is considered of vital importance for the basin management, particularly in the mitigation of floods and irrigation in Mozambique. On one hand, we applied V.I.S.A software to build the value measurement tree in order to understand the complexity of the problem whose resolution may lead to improvements in the economy, social, environmental, and coping mechanisms as shown in **Figure 5**. In **Figure 5**, we can see the progress achievable with respect to water supply, power supply, health issues, and the irrigation facilities for agriculture, which are in direct correlation to the different alternatives for the dam storage capacity, and which range from 2000 to 10,000 Mm^3.

The analysis of profiles for different sub-criteria by storage capacity also can be addressed in another chart, where we can aggregate them all together in the first section of the chart at most left of **Figure 6**. This is followed by a progressive analysis of scenarios with a dam of 2000 Mm^3 storage capacity where the environmental issues ranks last from worst to best, while the economy leads the process, this might result from new capacity of job creation and other social facilities. On the second scenario with a dam of 5000 Mm^3 storage capacity the economy leads followed by the coping mechanisms and social issues, while the environmental aspects ranks last in the process. The scenario of 10,000 Mm^3 storage capacity dam brings more reliable and consistent changes with coping mechanisms on the top, followed by economic and environmental issues while the social area ranks last. Notice that in this scenario, all four dimensions are above 75 units in the scale of the worst being 0 to the best being 100 units, respectively. The involved stakeholders should agree on the scale and the units to be used in advance.

In addition, some research done was based on the Decide IT software, with the main result represented in the decision tree in **Figure 5**. The tree shows two main branches for the feasibility of Mapai Dam project: two main outcomes are highlighted, alternative one with "Yes"

for the development of the dam and alternative two with "No," which means no action or not developing the project, hence no further developments in this branch.

Alternative one with the main sub-decision node E2 "dams of different storage capacities," which shows three main branches, namely for dams with storage capacities of 2000 Mm^3 with 40% probability to be developed, 5000 Mm^3 with 35% probability, and 10,000 Mm^3 with 25% probability, respectively. In the first two scenarios, E1 and E2, we have possibilities to perform basic and moderate improvements of water and power supply facilities, while the third scenario with 25% of chances might bring profound and significant changes in the water supply, power supply, irrigation for agriculture, and the job creation.

In short, **Figure 5** shows two main decisive moments: D1 and D2, which are represented by two green squares. D2 represents the preliminary step where the stakeholders choose whether to build the dam (alt one) or keep the actual situation (alt two). D1 represents a more developed stage, where different options have been developed and evaluated, see nodes E1, E2, E3, E4, and E5, which are part of key milestones to the process, nonetheless their results were not much feasible to meet the overall objectives, such as shown in the decisive node D1.

7. Conclusion and future work

This research shows how complex problems can be solved through the application of sophisticated tools and techniques, particularly a combination of them as we developed in this article. For a real case, using the support of both V.I.S.A and Decide IT we built different scenarios and simulated different outcomes; here the value measurement tree helped to understand and structure all features and details of the problem, while the decision tree enumerated all the possible outputs according to parameters such as the dam storage capacity. For this purpose we used probabilities of the stakeholders, even when those have different preferences. Here, we combined the inputs from the reviewed documents with those from the interviewed stakeholders in Chókwe. Additional analysis based on monetary values and probabilistic simulation could be developed as a part of sensitivity analysis, but this is beyond the scope of the present research, and, provided that our main aim was to evaluate the possible outputs and implications of building the dam, we limited our analysis at this stage. Given the limitations of data and time to perform more detailed research, for the present study, we will validate it in further research as part of the future work.

Author details

Avelino I. Mondlane

Address all correspondence to: si-aim@dsv.su.se

Department of Computer and Systems Science (DSV), Stockholm University Kista, Sweden and Center for Informatics, Eduardo Mondlane University, Maputo, Mozambique

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