CASE STUDIES

Algebra and Large-Scale Dam Assessment: The Case of Merowe Dam in Sudan

David Requejo Castro, Judit Taberna Torres and María Isabel García Planas

PHOTO: Merowe Dam inauguration. Sudan. Philip Dhill / EPA

GDEE GLOBAL DIMENSION IN ENGINEERING EDUCATION

CASE STUDIES

Algebra and Large-Scale Dam Assessment: The Case of Merowe Dam in Sudan

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2 ALGEBRA AND LARGE-SCALE DAM ASSESSMENT: THE CASE OF MEROWE DAM IN SUDAN

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1. INTRODUCTION

In 2015, world leaders adopted the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals[1] (SDGs). These new global Goals are unique in that they call for action by all countries - low, high and middle-income - to promote prosperity while protecting the planet (United Nations).

Sustainable development has been defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). For sustainable development to be achieved, it is crucial to harmonize three core elements: economic growth, social inclusion, and environmental protection. These elements are interconnected and all are crucial for the well-being of individuals and societies (United Nations).

Dams are often needed to achieve the social and economic dimensions of sustainable development, ideally serving multiple purposes including water supply [SDGs 6.1, 6.4] for agriculture [SDG 2], jobs and industry [SDGs 8, 9], domestic use [SDGs 1, 3, 5, 11], energy generation [SDG 7], and flood and drought protection [SDG 11.5]. Effective reservoir operation for multiple purposes requires the involvement of all sectors and stakeholders, which is supported by Integrated Water Resource Management (IWRM) [SDG 6.5] (UN-Water, 2016).

However, the construction and operation of dams can lead to potential conflict with ecosystems [SDGs 6.6, 15], in different sectors of water use, and between communities [SDG 11]. Further, impacts are often felt in downstream areas and countries. Conflicts can be reduced by ensuring public access to information [SDG 16.10] and by involving all stakeholders in design, planning, and operation [SDG 16.7] through the implementation of IWRM, including at the transboundary level [SDG 6.5]. Technical measures are also needed, such as adequate reservoir operation to ensure sufficient environmental flows to maintain ecosystems and fish migration [SDG 15.5] (UN-Water, 2016).

Through this case study, students will be asked to apply several algebraic contents in order to carry out a simplified design of a dam. The statements mentioned above will also be discussed, focusing on the construction of the Merowe dam, located in Sudan.

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[1] *Detailed information regarding the SDGs can be found at http://www.un.org/sustainabledevelopment.*

1.1. Disciplines covered

The specific topic covered in this case study falls on Markov chains. This concept is one of the most widely-used applications related to linear algebra, particularly in matrix operations.

Other themes of linear algebra that students that are likewise expected to be more deeply used are modelling, induction hypothesis methods, powers of matrices, diagonalization of linear maps, and the application of these to the resolution of discrete dynamical systems.

Finally, and considering the nature of the class activity, teamwork is promoted in this case study, with the aim of stimulating enriching debates in the classroom.

1.2. Learning outcomes

After completing this case study, students are expected to be able to:

- Improve their capacity of translating a context statement into algebraic terms;
- Increase their knowledge related to the interdependency of water with other human development aspects;
- Widen their perspective when analysing the complexity of a potential conflict associated to the professional practice of engineering.

1.3. Activities

In this case study, two activities are requested from the students. In the first, an enrichment debate will be encouraged by reflecting on the importance of water in human development and well-being and on the complexities associated with the construction of a large-scale infrastructure. For this, the context of the Merowe dam built in Sudan is explained. Further, a simplified problem regarding the design of a dam will be worked on the aim to translate it into algebraic terms.

The second activity, designed to be solved out of class, aims to go deeper into the presented problem by applying more advanced algebraic knowledge. In addition, students will be requested to provide an assessment of the results obtained in relation to the contextualization of the case study.

2. DESCRIPTION OF THE CONTEXT

In this main part of the case study, we provide a brief description of the complexities that encompassed the construction of the Merowe dam in Sudan. First, we briefly introduce the global perspective of the large-scale dam construction, describing the reasoning for such infrastructures and the potential interest in them. We then focus on Sudan, where the construction of the Merowe dam at the fourth cataract of the Nile River took place. Some relevant factors are provided to allow a simplified sketch of the country to be drawn. Finally, we describe several aspects in detail, such as the global actors involved and the impacts this has had at the environmental, social, and Human Rights levels.

2.1. BIG DAMS: A BRIEF GLOBAL PERSPECTIVE

In this section, we present a review of Verhoever (2012b) to provide a global perspective of hydro-infrastructure rationale and potential interests and impacts. Undoubtedly, this is a complex context, where several actors, distinct factors, and geographical regions come into play all together[2].

> “Big dams have long fascinated scientists and politicians alike, sitting at the intersection of water security, modernisation strategies and nationalism. They became popular in low income countries seeking to meet the triple challenge of state-building, nation-building and economic development. General Franco used dams and a powerful water-bureaucracy to re-centralise control over a fragmented, 'backward' nation after the Spanish civil war. Nehru saw dams as the "modern temples of India" lifting hundreds of millions out of poverty through spectacular multiplier effects in industry and irrigated agriculture. And Gamal Abdel Nasser advanced his revolutionary "second Egyptian independence" through the Aswan Dam: Africa's biggest infrastructure project controlled the Nile flood for the first time in history and symbolically catapulted Egypt into the club of advanced nations.
>
> Big dams were believed to magically transform barren wastelands into fertile acreage, elevating the nation and integrating, through irrigation and electrification, the domestic political economy. The World Bank provided the ideological and financial backing for the construction of hundreds of megadams across Latin America, Africa and Asia. Yet from the 1970s onwards, dams as development instruments were increasingly contested. Opponents exposed huge corruption scandals that contributed to the systematic

[2] *Recommendable lectures for detailed information regarding economic and political background in several dam construction initiatives can be consulted in Dirar et al. (2016) and Verhoever (2012a; 2011).*

overestimation of their benefits and the neglect of their dark side. Paradigmatic cases like the Sardar Sarovar in Western India forced the World Bank to largely withdraw its support for large-scale hydro-infrastructure: the displacement of tens of thousands of people, devastating environmental damage to unique ecosystems, and the undemocratic decision-making surrounding dams triggered a re-think. Many assumed that big dams might be shipped to a museum for 20th century illusions of development - with Western funding drying up, their role in economic growth strategies seemed over.

However, in 2012, dams were staging an impressive comeback, as hundreds of new projects had commenced in the last few years. China, India and Brazil – not coincidentally also the three most important rising powers – are the world's top three dam-builders, each with domestic megaprojects of its own, but also increasingly a proactive role in an emerging global political economy of food and water. Beijing especially was using its formidable technical expertise in hydro-infrastructure and immense foreign reserves to resurrect dam-building overseas: in half of all African countries, from the Sudanese desert and the Ethiopian lowlands to the rivers of Algeria and Gabon, Chinese engineers were involved in the planning, heightening and building of more than 100 dams. The tens of billions of US dollars and thousands of megawatts involved in these projects have so far remained off the radar in the China-Africa debate but are possibly more consequential for the future of the African continent than the exports of oil, copper and other valuable resources.

As the global balance of power shifts eastwards, supply and demand networks are restructured, resulting in tremendous pressures on commodity prices and scarce resources. Dams are therefore no longer merely central to the debate about economic development but also an integral part of water and food security strategies. Food prices especially have spiked, bringing riots in their wake; this has led many to predict that land and water are becoming the world economy's Achilles heel. Emerging powers are seemingly racing to secure the key resources of the future. Big investments by Gulf Arab sovereign wealth funds, purchasing strategies of land by South Korean and Malaysian enterprises and China's involvement in African dam-building cannot be seen in isolation from growing fears about how to ensure water security in the 21st century.”

2.2. Sudan at a glance

Sudan, also known as North Sudan (after south Sudan's independence in 2011 following the Sudanese Civil War; south Sudan is now officially the Republic of the Sudan) is a country in Northern Africa bordered by Egypt to the north, Libya to the northwest, Chad to the west, the Central African Republic to the southwest, South Sudan to the south, and the Red Sea Eritrea and Ethiopia to the east. It is the third largest country in Africa, with an estimated population of approximately 40 million people (UN-DESA, 2017) and an area of 1,886,068 km^2. The Nile River divides the country into eastern and western halves. Its predominant religion is Islam.

Figure 1 *Geographical location of Sudan. Sources: www.wikipedia.org; www.alamy.com.*

As reflected in the Human Development Report (United Nations Development Programme, 2016), Sudan has a Human Development Index[3] (HDI) of 0.490, which puts it in the group of countries with low HDI, and ranks as the 165 county (out of 185), after Uganda and before Togo and Benin. Although no data are available to calculate other development indices, Sudan does not reflect itself as an unequal country, with a GINI coefficient[4] of 0.35 (where a value of 0 means that everyone has the same income, and a value of 1 means that one person has all the income).

Social issues

As reflected in the African Economic Outlook (2017), a United Nations Children Fund (UNICEF) report (2014) indicated that more than three million school-age children need have life-sustaining education. A report by the Ministry of Education (2015) found high dropout rates that average 6% and 8% for primary and secondary levels, respectively. The UNICEF report (2014) showed that only 40% of the education sector's needs are funded. These outcomes call for further measures to meet the Sustainable Development Goal (SDG) target 4 on high quality primary and secondary free education by 2030.

[3] *Detailed information regarding index construction at http://hdr.undp.org/en*
[4] *More information can be found at http://data.worldbank.org/indicator/SI.POV.GINI*

The Outlook Report of 2017 continues to emphasise that females made up 49% of the population according to the latest Labour Household Survey (2011). Although Sudan’s 2005 Constitution enshrines female emancipation from injustice, promotes gender equality (including in wages), and encourages the role of females in family and public life, gender discrimination is rampant because of the lack of implementation capacity and civil conflicts, as well as cultural and social values. More than 90% of females in the country have been subjected to female genital mutilation; 48% of them are illiterate, as compared to 12% for men; and their rate of participation in the labour force is 14.1% as compared to 38.4% for males. Sudan is among the poorest ten performers on the Gender Inequality Index[5] (GII), with a ranking of 135th out of 155 countries in 2014.

Environmental issues

The amount of rainfall increases towards the south. The central and the northern part have extremely dry desert areas, such as the Nubian Desert to the northeast and the Bayuda Desert to the east; in stark contrast, there are swamps and rainforests in the south.

The dry regions are plagued by sandstorms, which can completely block out the sun. In the northern and western semi-desert areas, people rely on the scant rainfall for basic agriculture, and many are nomadic, travelling with their herds of sheep and camels. Nearer to the Nile River, there are well-irrigated farms growing cash crops.

Economic issues

In 2010, Sudan was considered the 17th fastest-growing economy in the world, and the rapid development of the country largely from oil profits. Because of the secession of South Sudan, which contained over 80% of Sudan's oilfields, Sudan entered a phase of stagflation (a situation in which the inflation rate is high, the economic growth rate slows, and unemployment remains steadily high). Currently, agricultural production remains Sudan's most-important sector, employing 80% of the workforce and contributing to 39% of the gross domestic product (GDP), yet most farms are rain-fed and thus susceptible to drought. Instability, adverse weather, and low worldwide agricultural prices ensure that much of the population will remain at or below the poverty line for years to come.

[5] *Detailed information regarding index construction at http://hdr.undp.org/en*

Governance issues

As explained in Dirar et al. (2015):

> "Hydro-infrastructure construction on the Nile is closely related to the consolidation of political and economic power by the ruling elites. The establishment of the Anglo-Egyptian Condominium in 1898 in Sudan was largely hydro-political, as Britain sought to extend its control of the Nile waters to feed its expanding textile industry at home (Waterbury, 1979). … Immediately after independence in 1956, the elites that enjoyed great economic and political benefits during the years of the Condominium charge of the new nation, replacing the British but maintaining the status quo, albeit with considerable political economic and institutional decay (Harir, 1994).
>
> The year 1989 signalled in the rise to power of Sudan's current Islamist regime known as Harrakat al Islamiyya, with its fundamental project of economic salvation or Al-Injaz. The Injaz regime was propelled by belief that political hegemony was consolidated through economic salvation. As before, the hydro-agricultural base would be the main mobilized resource to achieving this aim. After the downfall of former President, the latter would take the hydro-agricultural ambitions to a new chapter through Sudan's Dam Programme (SDP) and its accompanying Agricultural Revival.
>
> The Injaz maintained the image of an Islamist regime although it shifted the emphasis of legitimizing their seat in power from ideological - radical Islamism, to economic - business partnership. The imperative factor to continued political control of the regime was now in its delivery of economic and developmental success.
>
> The official birthdate of Sudan's Dam Programme can be said to correspond with the establishment of the Dam Implementation Unit (DIU) in 1999. Brought into existence under presidential mandate - specifically for the construction of the Merowe Dam - the DIU is unlike any other state institution in Sudan. … The nature of the DIU as a governmental institution is unique, and the power that it yields is exceptional. Although it was founded to implement the plans for the Merowe dam, it was promoted into a fully-fledged presidential department. Its jurisdiction extends beyond the purview of dam construction and irrigation into construction works (roads, hospitals, bridges and airports), agricultural development works, electricity provision, preparations and executions of funding activities, and control over its own multi-billion dollar budgets."

2.3. The Merowe dam

Purpose and construction

> “The Merowe hydropower dam was built between the years of 2003–2009 by the National Congress Party of the Islamist Al-Injaz (The Salvation) government in Sudan, and implemented by the Dams Implementation Unit (DIU).
>
> The main purposes for Merowe were hydropower generation, with an operating capacity of 600 MW (total designed capacity 1,200 MW), and irrigation—concurrent with plans for developing centralized agricultural schemes of 300,000 ha. It contains a reservoir of 12.5 km^3, or about 20% of the Nile's annual flow.
>
> The electrical power generated by the dam is considered and lauded as the greatest imperative by technocratic advocates, as the country’s shortages are seen as a great obstacle to development. Current electricity demand across the country greatly outstrips supply. Hydro-electricity provided 50% of electricity in the national grid in the late 1990s and is expanding through new dams and refurbishments of old dam projects. Expanded energy production may not lead to equal distribution, as currently 70% of the available electricity is consumed by the capital, while rural areas are undersupplied (Bosshard and Hildyard, 2005)” (cited from Dirar et al., 2016).

The dam is one aspect of the DIU development plans for Merowe and is in conjuncture with a number of accompanying projects to the region. This includes residential towns, roads and bridges, railways, an airport, and a hospital. However, several studies concluded that the dam has low feasibility (for example, an SWECO finding showed that the feasibility of realizing the agricultural purpose for Merowe were low). Despite its significant environmental, ecological, and social shortcomings, the German company Lahmeyer International provided the project with the technical and generally positive Environmental Impact Assessment (EIA) it required to signal the project’s fundraising and construction stages. The positive assessment is suspected to arise from Lahmeyer’s secondary role as the primary consultant for the project—posing a clear conflict of interest, and the company has since been implicated in fraud and corruption charges. After many years of obstacles for Merowe, in the form of discouraging studies and difficulty of finding willing financers, the project finally had the green light of an EIA in 2002, and funding opportunities were provided in the form of domestic oil-export revenue as well as Gulf Arab States and Chinese interest (Dirar et al., 2015).

Figure 2 *Up: Merowe Dam location and infrastructure*[6]*. Down: Turbine details*[7]*.*

Global actors

As pointed out by Dirar et al. (2015), the main global players nurturing the Sudanese "development" and dam-building efforts were the Gulf Arab States, Egypt, and China, through financial investment, construction support, and political support. The author states that foreign investment in Sudan was motivated by various global factors, and that the growing involvement of China in the foreign investment-banking sector was coupled with its increased role in the global dam-building industry, which was of particular significance in African states.

The literature review provided by Dirar et al. (2015) states that Arab Gulf Funds supporting Sudan's hydro-agricultural developments was understood in the global context of rising food prices, concerns with resource limitations, and the desire to secure overseas food production. It follows that hundreds of thousands of fertile lands in North Sudan was being leased to these Arab states under private business agreement. Furthermore, Arab states' investment was arguably influenced by Sudan's alliance with Egypt and the promise of an

[6] *Sources: www.wikipedia.org; english.cntv.cn*
[7] *Sources: www.skyscrapercity.com; www.flickr.com*

Arab-Islamic identity of the nation. Arab political and economic interest was responsible for the financing of Merowe and ten other large hydro-infrastructure projects.

Indeed, Egypt has confirmed that its political support for Sudan's dam initiatives was driven by its perceived national benefits from these projects. Firstly, in light of the emergence of the Nile Basin Initiative (NBI) in 1999, which posed a serious threat to the downstream state's control over upstream use of the flows, Egypt recognized the importance of Sudan as an ally in negotiations. Secondly, population pressures within Egypt and resource limitations to food production had been driving forces behind cooperation with Sudan in the realm of migration, labour, and agriculture. Egypt and Sudan had made arrangements to allow the free flow of labour between the two nations, although in reality, that mainly meant an influx of Egyptian settlers on Sudan's prime irrigated riverside farmland.

Constructors

Construction began in 2003 after contracts were signed with various international companies for different sections of the dam's construction. As previously mentioned, Lahmeyer International (German) was the main company offering consultancy services throughout the dam's design and implementation phases. The Chinese multinational dam building company, Sinohydro, provided technical input in the form of a large number of highly skilled engineers for the implementation of the Merowe dam. Other international companies involved in Merowe were CMMD (Chinese consortium), tasked with the construction of the accompanying dam structures and related services; Harben Power Engineering (China), responsible for building all the transmission lines and substations; Alstom (French), in charge of manufacturing and installing the dam's 10 turbine units; and ABB (German-Austrian), awarded with the contract for designing and installing the transmission system.

Funders and financers

As detailed by the DUI, the summary of investors are shown in *Table 1*:

Table 1 *Investors of the Merowe Dam. Source: Dams Implementation Unit, 2007.*

INVESTOR	FUND (Million $US)
Government of Sudan	1,114
Government of China	608
Arab Fund for Economical and Social Development	477
Saudi Fund for Development	215

Abu Dhabi Fund for Development	210
Kuwaiti Fund for Economical Development	200
Sultanate of Oman	106
State of Qatar	15
Total	**2,945**

2.4. Environmental, Social and Human Rights Impacts

Environmental impacts

Sudan's Environmental Protection Act 2001 requires that projects such as the Merowe Dam have an Environmental Impact Assessment (EIA), and that construction should not begin until the EIA has been reviewed and approved by the Government's Higher Council for Environment and Natural Resources (HCENR). Although an EIA was belatedly undertaken for the project by Lahmeyer in 2002, it was short, superficial, and incomplete (Hildyard, 2008). This was confirmed by an independent review of the EIA conducted by the Swiss Federal Institute of Aquatic Science and Technology (EAWAG) in 2006 (Dirar et al., 2016).

The main conclusions of EAWAG's review on the environmental shortcomings of Lahmeyer's EIA of the Merowe Dam include the inadequately assessed risks of sedimentation, greenhouse gas emissions from decomposing organic matter, biodiversity loss and disrupted fish migratory patterns, irrigation (in)feasibility, and deteriorating water quality. It concluded that the trapped sediments (estimated at 130 million tons yearly) would result in a reduction of power-generating capacity of 39% over the next 50 years. Others predict a shorter life span, of 20 years, before total loss of capacity (Verhoeven, 2012a).

The environmental impacts have attracted national concern and studies as well, with a key study by Seif al-Din Hamad (2007), a former minister of irrigation, investigating potential evaporation loss of proposed and constructed dams. The study concluded that if all the planned dams were implemented, Sudan would be faced with serious water shortages for agricultural extension (Seif al-Din Hamad, 2007; cited by Dirar et al., 2016). National experts also express broader environmental concerns of the environmental and ecological irrationality of dams in Sudan, which are threatened by redundancy and short reservoir capacities due to the river´s hydrology and high rate of sedimentation.

Social impacts

The area inundated by the Merowe dam was home to over 60,000 Manasir inhabitants and 10–15,000 inhabitants from Amri and Hamdab communities. Life on the fourth cataract (location of Merowe dam) has traditionally been dominated by small-scale agriculture on the alluvial soils, which border the banks of the Nile. The most important crop to the Manasir, both economically and culturally, is date palm. Date trees are also deeply connected with cultural pride and belongings, and is a symbolic object of cultural reverence. The monetary valuation of date trees is traditionally inconceivable, and various "economic, cultural and social factors result in a practical inconceivability of selling palm trees as real assets among the Manasir" (Haberlah, 2005; cited by Dirar et al., 2016). Prior to the construction of the Merowe dam, the implication of the dam on the life of the Manasir and the issue of displacement and resettlement has been discussed within the communities, with much controversy and differing views. Despite inter-community discussions and debate over the Merowe dam, the people largely were unaware and uncertain as to the details of the extent of the damages and relocation arrangements. Many held hopes that they would not be badly affected and assumed that they would remain in the region by moving to higher grounds (Dirar et al., 2016).

The arrangements for the compensation and resettlement plans and their implementation were conducted by the same authority in charge of the dam itself—the DIU. The official claims of the project authorities and the Lahmeyer EIA was that resettlement offered great opportunities to improve the living standards of the affected populations, and were planned with a development-oriented approach in mind. Many of the Hamdab, Amri, and Manasir people initially welcomed and accepted the dam's construction. Their initial consent to the project became qualified or changed completely, with time, to the point today that a majority are greatly disappointed.

The Hamdab people were the first group to be resettled in June 2003, as they lived immediately behind the site of the dam. They accepted the resettlement arrangements set out for them and moved approximately 100 km down the river from their homeland and far from its shore. A joint International Rivers Networks and Corner House report concluded that rapidly deteriorating conditions were contributing to worsening poverty (Hildyard, 2008). Unfair compensation for lost assets and attempts of the project authorities to dwarf the people's entitlements, combined with conditions of poor soil quality and failing agricultural production, reportedly increased the poverty rate from 10% to 65% in the period of two years. The agricultural projects resettled farmers engaged in at the new site failed repeatedly, due to failing irrigation schemes. Water shortages continued to plague the resettlement site in 2014 (Dirar et al., 2016).

Based on the experiences of deteriorating conditions the Hamdab people faced, the Amri and Manasir groups were more cautious in accepting the arrangements set up for them by the dam authorities. Whilst some of the people from these groups accepted resettlement, a large proportion resisted and demanded to alternatively be resettled close to the reservoir's shoreline. Those that declined the official plans opted for an option proposed by their representative committees known as the "local option". A few days after the decisions were released, the head of the DIU appeared on television making a mockery of the decisions and indicating the weak chances of the successful implementation of the "local option". Frustrated by lack of recognition of their demands and the futility of formal bureaucratic engagement, the affected people strengthened their resistance through peaceful, and later, armed struggles to realize their aims.

In brief, the compensation and resettlement experience was characterized by a lack of transparency and consultation of affected people, and a shocking disregard by the DIU of the formal negotiations between the Committees of the dam affected peoples (DAPs) and State officials and ministries. In a manner similar to the execution of the EIA, the absolute power granted the DIU by the presidency ensured the outcome.

Human Rights impacts

The communities affected by the Merowe project have consistently stated that they are not opposed to the dam on principle but that they wish to see their rights to just resettlement and compensation respected. Peaceful protests to achieve these ends, however, have repeatedly been met with force. Critics of the project have also been subject to arbitrary arrests, intimidation, and torture (Hildyard, 2008). The most severe event took place in 2006, where a protest of the Amri population resulted in the death of three citizens and injury to more than 50[8].

Although the companies have been informed of such abuses, they have (with the exception of ABB) either stood resolutely on the sidelines, refusing to intervene, or have sided with the authorities. Responding to the April 2006 shootings at Amri, for example, the China International Water and Electric Corporation issued a statement denying that any disturbances had taken place. Lahmeyer acknowledged that shootings had taken place but placed the blame on "a group of landless protestors" who attacked officials who were attempting to deal with compensation disputes. Alstom remained silent on the massacre. Only ABB acted, expressing its concern directly to the Sudanese authorities, calling for "a full inquiry and for the results to be made public".

[8] *More information related to reported violent events can be found in Hildyard (2008).*

3. CLASS ACTIVITY

The proposed class activity aims to encourage a debate around the context that involved the construction of the Merowe dam. In so doing, several questions will be put into play as a starting point. In this sense, it is recommendable to provide the students with that material in advance. On the other hand, a simplified problem associated to the design of a dam will be proposed to the students in order to learn how to translate it into algebraic terms. This is especially relevant, as it will provide the base for carrying out the homework activity.

This class activity is divided in two sections or blocks, with a total duration of about two and a half hours. As far as the methodology, we propose that students work in small groups (i.e. 3 to 4 people); further details are given in each block of the activity.

Class activity: Block I

The first part of the class activity, programmed for one and a half hours work, proposes to reflect on several of the aspects introduced in this case study. For this, a group discussion is encouraged to take place in every group after the first half (at 45 minutes). To conclude the activity, a general debate of 45 minutes is recommended to put all points of view together.

First, a simple question is asked to the students:

- Which is the aspect (from all the circumstances, impacts, and facts that you have been presented) that most attracted your attention?

Second, the following questions are presented for encouraging further debate:

- If a company supplies turbines for a hydroelectric dam, does it have a responsibility, legal or moral, to ensure that the dam's environmental and social impacts are minimized?

- Or do its ethical policies and legal obligations extend only to ensuring that the manufacture of the turbine is environmentally sound and without human rights impacts?

- What about other actors involved in the dam or any other project?

- For example, banks and financial institutions - do they have a duty to ensure that the money they provide for projects does not facilitate adverse environmental impacts and human rights abuses?

Finally, a brief analysis of the direct and indirect impacts (positive or negative) associated with dam construction is requested from the students. For this, *Table 1* should be filled out. As stated, this analysis must be done considering the social, environmental, and economic dimensions.

Table 1 *Proposed dimensions on which to base the discussion about potential direct and indirect impacts of a dam construction.*

DIMENSION	DIRECT IMPACTS	INDIRECT IMPACTS
Social		
Environment		
Economy		

Class activity: Block II

This second part will take another hour of work. We suggest maintaining the same working groups. For this block, we propose using the following example:

The Government of Sudan plans to build another reservoir to regulate the basin of one of its rivers to meet water requirements for irrigation. The maximum expected dam capacity will be 5,000,000 m^3 (5 km^3), or abbreviated, 5 units of water (1 unit of water = 1,000,000 m^3). The Merowe dam contains a reservoir of 12.5 km^3 (20% of the Nile's annual flow). Before proceeding to construction, the Government would like to have some idea about the effectiveness of the dam over the long term. In so doing, a study analyzed the yearly volumes of water provided by the river and has found that they can be approximated using the following distribution of discrete probability:

Yearly contribution in units of water	2	3	4	5	6
Probability	0.2	0.4	0.2	0.1	0.1

The Government is considering the possibility of making irrigation contracts that will require the consumption of 2 units of water per year. However, in order to maintain water quality standards for other uses, 1 unit of water per year must be kept constantly. Therefore, the yearly goal will be to let out 3 units of water. If the state of the reservoir (level of the reservoir) plus the water intake of the river is less than this amount, less quantity of water must be let out, thus affecting the irrigation schemes. If the reservoir is full, any excess will be taken through the spillways (surplus water dumps). The minimum permitted level of the reservoir (minimum state) may not be less than 1 water unit.

Students should now model the problem using a discrete linear dynamical system—that is to say, through the use of a matrix equation of type p(k+1) = A·p(k), describing the probable yearly transition of the units of water. As the whole solution of the problem will be left for the homework activity, only the solution for the case of having one unit of water should be presented in Block II.

3.1. Solution and evaluation criteria

Class activity: Block I

There is no a specific solution for this activity, as it is an open-answer one. The main idea is to give students the chance to present and defend their arguments. This statement is more related to the first and second set of questions.

On the other hand, students have been provided with a brief guide of potential impacts of a dam construction. Although a deeper analysis could be done, the objective is to offer the professor a tool to facilitate the debate as the moderator (in the case that there is a lack of participation).

DIMENSION	DIRECT IMPACTS	INDIRECT IMPACTS
Social	- Water supply for domestic purposes - Displacement of people - Disappointment of citizens	- Improving human health and well-being - Losses of personal roots; change in life dynamics - Dissatisfaction with political system; potential violent conflicts
Environment	- Flood and drought protection for humans - Potential ecosystem damage - Clean energy generation	- Alteration of environment initial state - Increasing the possibility of a natural point of no return - Reducing GHG (greenhouse gases) emissions
Economy	- Water supply for agriculture and industry - Job creation - Energy provision - Mobilizing economic market	- Improving economic activity; ensuring food security - Increasing people's power purchase - Improving human well-being and promoting economic growth; promoting transboundary businesses - Business development; potential corruption

Class activity: Block II

Let's call k = years

$p_i(k)$, where i = 1; 2; 3; 4; 5, it is the probability of the dam to have i units of water in the year k.

The matrix A = (p_{ij}) where p_{ij} denotes the probability that having j units in the year k, there are i units in the year k + 1.

In order to calculate p_{ij} (when j = 1), the starting point is set as the point at which the dam's level is equal to 1 unit of water. Then, and considering the possible river contributions, the different states of the dam, in terms of capacity, are calculated. Finally, and taking into account the conditions established in this activity (minimum and maximum levels, and quantity for irrigation), the final level of the dam after water provision can be obtained. The following table represents this line of reasoning.

Units in year k	Water entrance	Probability	Dam state after water entrance	Water provision	Units in year k + 1
1	2	0.2	3	2	1
	3	0.4	4	3	1
	4	0.2	5	3	2
	5	0.1	6	3	3
	6	0.1	7	3	4
Result: $p_{11} = (0.2 \times 1) + (0.4 \times 1) = 0.6$					

Thus, as evident from the previous table, when the initial capacity is 1 unit of water (year k), the final level (year k + 1) will be equal to 1 unit when the water entrance is 2 or 3 units of water. Thus, the dam's probability to reach 1 unit capacity is 60% (0.6), which corresponds to the probability sum of the water entrance of 2 or 3 units of water.

Units in year k	Water entrance	Probability	Dam state after water entrance	Water provision	Units in year k + 1
2	2	0.2	4	3	1
	3	0.4	5	3	2
	4	0.2	6	3	3
	5	0.1	7	3	4
	6	0.1	8	3	5
Result: $p_{12} = 0.2 \times 1 = 0.2$					

Units in year k	Water entrance	Probability	Dam state after water entrance	Water provision	Units in year k + 1
3	2	0.2	5	3	2
	3	0.4	6	3	3
	4	0.2	7	3	4
	5	0.1	8	3	5
	6	0.1	9	4	5
Result: $p_{13} = 0$					

For the results, when i is equal to 4 and 5, it will be equal to zero as well. In this sense, the results obtained represent the first raw of the 5×5 matrix that it will be obtained (0.6; 0.2; 0; 0; 0).

Evaluation criteria

In order to provide an objective and transparent evaluation system for students, we propose to use a rubric (see *Annex I*). In this sense, the rubric shows: i) the knowledge that students are expected to acquire; and ii) the criteria used to evaluate the content of the answers associated with the proposed activities.

To use this rubric, first provide it to the students in order to inform them how they will be evaluated. Giving the students some guidance may be necessary to allow them to focus on the specific goals (in terms of answers).

To facilitate evaluation, each group must submit (or give in paper format) the answers to the professor at the end of the class. These answers will be evaluated based on the criteria of the rubric. However, the teacher is free to choose an alternative evaluation method that might be considered more appropriate.

4. Homework activity

As for the previous activity, homework is recommended to be done in small groups (i.e. 3 or 4 students). However, the teacher can make the final decision. In total, we estimate that the whole activity will need an effort of 10 hours work.

The starting point of this activity is the problem presentation introduced in the class activity second block. Now, students are requested to work on the following tasks:

- Obtain the remaining terms p_{ij} and specify how this process was carried out. In addition, the resulting system should be presented;
- Assuming that the initial situation of the dam is related to a level of 3 units of water, what is the probability to be at the minimum level two years later?
- Study the asymptotic behaviour of the system. Is the dam sustainable?
- Provide an assessment in the context of the problem, in terms of results and knowledge acquired.

4.1. Solution and evaluation criteria

Obtain the remaining terms p_{ij} and specify how this process was carried out

The problem exposes a set of conditions that should be presented along with all calculations and procedures effected. Thus, it is necessary to consider that the maximum capacity of the reservoir is 5 units of water, and that the minimum level admitted is 1 unit of water (with 1 unit = 1,000,000 m^3). Thus, if the reservoir level plus the yearly contribution from the river is lower than 3 units, a lower quantity of water should be extracted, as the minimum level must be maintained. This fact will produce a deficiency in the irrigation scheme.

The initial level of water can be 1, 2, 3, 4, or 5 units (first column of the following tables). In each one of the cases, there is a contribution of river water of 2, 3, 4, 5 or 6 units, with the probability stated in the problem (second and third columns, respectively). The state of the reservoir corresponds to the sum of the initial state and the yearly river contribution (fourth column). Now, 3 units are extracted from each case, such that the final level of the reservoir corresponds to the state of the reservoir minus 3 units (fifth column).

At this point, it is necessary to be careful. No just any value can be accepted for the final level of the reservoir, as the minimal restrictions must be respected. Thus, the final value can only be 1, 2, 3, 4, or 5 units of water (as the minimum level is 1 unit, and the maximum, 5). The last column of the table ("observations") represents whether or not the final dam level is acceptable.

Thus, when the reservoir state is ≤ 3, the final level will be 1; in other words, the irrigation needs will not be satisfied. On the other hand, when the reservoir state is ≥ 9 units, the final level will be 5, as that is the maximum capacity. More units than strictly necessary will be extracted, and therefore excessive units of water will be poured out. To calculate the number of units of water that are excessive, it is necessary to subtract 8 units (5 corresponding to the capacity of the reservoir, and 3 corresponding to the aim of the problem) to the state of the reservoir. With all these considerations in mind, the associated tables are presented below:

Units year k	Water entrance	Probability	Dam state	Water provision	Units year k + 1	Observations
1	2	0.2	3	2	1	Needs not met
	3	0.4	4	3	1	Correct
	4	0.2	5	3	2	Correct
	5	0.1	6	3	3	Correct
	6	0.1	7	3	4	Correct

Units year k	Water entrance	Probability	Dam state	Water provision	Units year k + 1	Observations
2	2	0.2	4	3	1	Correct
	3	0.4	5	3	1	Correct
	4	0.2	6	3	2	Correct
	5	0.1	7	3	3	Correct
	6	0.1	8	3	4	Correct

Units year k	Water entrance	Probability	Dam state	Water provision	Units year k + 1	Observations
3	2	0.2	5	3	2	Correct
	3	0.4	6	3	3	Correct
	4	0.2	7	3	4	Correct
	5	0.1	8	3	5	Correct
	6	0.1	9	4	5	Excess through spillways

Units year k	Water entrance	Probability	Dam state	Water provision	Units year k + 1	Observations
4	2	0.2	6	3	3	Correct
	3	0.4	7	3	4	Correct
	4	0.2	8	3	5	Correct
	5	0.1	9	4	5	Excess through spillways
	6	0.1	10	5	5	Excess through spillways

Units year k	Water entrance	Probability	Dam state	Water provision	Units year k + 1	Observations
5	2	0.2	7	3	4	Correct
	3	0.4	8	3	5	Correct
	4	0.2	9	4	5	Excess through spillways
	5	0.1	10	5	5	Excess through spillways
	6	0.1	11	6	5	Excess through spillways

Once the problem is analyzed, it will be defined using the matrix equation of $p(k+1) = A \cdot p(k)$.

Let’s define k as the years passed, p(k) as the probability of the initial state of the reservoir), and p(k+1) as the probability of the reservoir state a year later. Additionally, A is defined as the matrix of transition obtained by using the chain of Markov.

To find the A matrix, it is necessary to focus on the tables generated previously, and specifically, the columns related to the initial level (k) and the final level (k + 1) of the reservoir, and the probability of river contribution.

Each row of the A matrix refers to the final level of the reservoir, and each column expresses the initial level. As there are 5 initial states and 5 distinct final states, the A matrix will have the dimension 5×5. Each element of the matrix indicates the probability of beginning with a determinate initial level of water and finishing with another. In order to find each element, the volume contributed by the river should be analyzed. For example, to focus on the first row, which is associated with a final level of 1 unit of water, the following should be done:

In the first-year table, examine the column of the final levels (Units year k + 1) to find the value of 1 unit; note that river contributions of either 2 or 3 units (water entrance) gives a final level of 1. The probability of finishing the year with 1 unit of water in the reservoir is 20% if the river feeds in 2 units of water, and 40% if the river feeds in 3 units of water. Therefore, there is a 60% of probability to begin with 1 unit of water and finish with 1 unit (e.g., if the probabilities 20% + 40% are summed). This value corresponds to the element of the first row and the first column of the A matrix.

For the second term of the A matrix, the first row will correspond to the total probability of having an initial unit of water level of 2, and a final level of 1. This probability is 20%, as it is only achieved when the contribution is 2 units of water. Finally, the remaining terms of the first row correspond to 0, since there is no situation in which the reservoir has an initial level of 3, 4, or 5 units of water and finishes with a final level of only 1 unit of water (zero probability). To complete all the elements of the matrix, the procedure should be repeated for each value of the initial and final levels. For this, the following equations should be applied:

- $p1(k+1) = 0.6 \cdot p1(k) + 0.2 \cdot p2(k) + 0 \cdot p3(k) + 0 \cdot p4(k) + 0 \cdot p5(k)$
- $p2(k+1) = 0.2 \cdot p1(k) + 0.4 \cdot p2(k) + 0.2 \cdot p3(k) + 0 \cdot p4(k) + 0 \cdot p5(k)$
- $p3(k+1) = 0.1 \cdot p1(k) + 0.2 \cdot p2(k) + 0.4 \cdot p3(k) + 0.2 \cdot p4(k) + 0 \cdot p5(k)$
- $p4(k+1) = 0.1 \cdot p1(k) + 0.1 \cdot p2(k) + 0.2 \cdot p3(k) + 0.4 \cdot p4(k) + 0.2 \cdot p5(k)$
- $p5(k+1) = 0 \cdot p1(k) + 0.1 \cdot p2(k) + 0.2 \cdot p3(k) + 0.4 \cdot p4(k) + 0.8 \cdot p5(k)$

It should be mentioned that $p_1(k)$ expresses the probability of initially having 1 unit of water; $p_2(k)$, the probability of having 2; and so forth. The result could be represented as follows:

$$A=\begin{pmatrix} 0.6 & 0.2 & 0 & 0 & 0 \\ 0.2 & 0.4 & 0.2 & 0 & 0 \\ 0.1 & 0.2 & 0.4 & 0.2 & 0 \\ 0.1 & 0.1 & 0.2 & 0.4 & 0.2 \\ 0 & 0.1 & 0.2 & 0.4 & 0.8 \end{pmatrix}$$

$$\begin{pmatrix} p1(k+1) \\ p2(k+1) \\ p3(k+1) \\ p4(k+1) \\ p5(k+1) \end{pmatrix} = \begin{pmatrix} 0.6 & 0.2 & 0 & 0 & 0 \\ 0.2 & 0.4 & 0.2 & 0 & 0 \\ 0.1 & 0.2 & 0.4 & 0.2 & 0 \\ 0.1 & 0.1 & 0.2 & 0.4 & 0.2 \\ 0 & 0.1 & 0.2 & 0.4 & 0.8 \end{pmatrix} = \begin{pmatrix} p1(k) \\ p2(k) \\ p3(k) \\ p4(k) \\ p5(k) \end{pmatrix}$$

Probability of having a minimum level 2 years later (assuming an initial capacity of 3 units of water)

From the A matrix obtained previously, it is possible to express p(k) as a function of p(0), that is, the general term of the vector succession defined by recurrence.

Considering the relation between the initial condition p(0) and the first year p(0+1), which is p(1), the resultant matrix would be:

$p(1) = A \cdot p(0)$

Then, considering the relation between the first and second years, the following is obtained:

$p(1+1) = A \cdot p(1)$ or $p(2) = A \cdot p(1)$

So,

$p(2) = A \cdot p(1) = A \cdot [A \cdot p(0)] = A^2 \cdot p(0)$

Likewise, the relation between the remaining years can be found:

$p(3) = A \cdot p(2) = A \cdot A2 \cdot p(0) = A^3 \cdot p(0)$

Therefore, it is possible to deduce the general form of p(k) as a function of p(0):

$p(k) = A^k \cdot p(0)$

To prove the veracity of this expression, Markov chain is applied.

$p(k+1) = A^{k+1} \cdot p(0) = A^{k} \cdot A \cdot p(0) = A \cdot p(k)$

Replacing $A^{k} \cdot p(0) = p(k)$, it is indeed seen that $p(k+1) = A \cdot p(k)$, which demonstrates the expression on hand.

To solve this, we can observe that p(2) = A · p(1) = A(A · p(0)) = A2 · p(0); then:

$$A^2 = \begin{pmatrix} 0.6 & 0.2 & 0 & 0 & 0 \\ 0.2 & 0.4 & 0.2 & 0 & 0 \\ 0.1 & 0.2 & 0.4 & 0.2 & 0 \\ 0.1 & 0.1 & 0.2 & 0.4 & 0.2 \\ 0 & 0.1 & 0.2 & 0.4 & 0.8 \end{pmatrix}^2 = \begin{pmatrix} 0.6 & 0.2 & 0 & 0 & 0 \\ 0.2 & 0.4 & 0.2 & 0 & 0 \\ 0.1 & 0.2 & 0.4 & 0.2 & 0 \\ 0.1 & 0.1 & 0.2 & 0.4 & 0.2 \\ 0 & 0.1 & 0.2 & 0.4 & 0.8 \end{pmatrix}$$

$$p(0) = \begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{pmatrix}$$

$$A^2 p(0) = \begin{pmatrix} 0.04 \\ 0.16 \\ 0.24 \\ 0.22 \\ 0.34 \end{pmatrix}$$

The obtained result permits us to conclude that there is a 4% probability of reaching the minimum level according to the initial conditions. On the other hand, there is a higher probability of achieving a final level of 3, 4, or 5 units of water than a low or minimum level (2 or 1 units, respectively). Specifically, there is an 80% probability of reaching a high level of the dam after two years, taking into account the initial condition of 3 units of water.

Asymptotic behaviour of the system (dam sustainability)

Asymptotic behaviour refers to the tendency of the water amount stored. In order to analyze the evolution of the water level, the limk Ak should be calculated.

For this, the eigenvalues of matrix A are calculated:

1.0000, 0.7685, 0.4553, 0.1129, 0.2633

Taking into account that there is a unique eigenvalue of module 1, and that the rest have a module strictly less than 1, the normalized eigenvector v1 (corresponding to eigenvalue 1) needs to be obtained.

v1 = (0.0194, 0.0388, 0.0971, 0.2427, 0.6020)

Then, $\lim_k \cdot A^k = v1$

Unlike stability, the concept of sustainability is not defined mathematically. In this sense, each student should assess whether the probability of the dam's water level makes it sustainable, and they should weigh this together with all other aspects.

Results assessment

Some aspects to be considered are presented here for the obtained results. While numerical results should be presented by the students, the assessment associated with the context is an open-answer. Ideally, students should link the information presented in this case study with the numerical results.

First, it is possible to affirm that the calculations carried out show that, regardless of the initial situation of the dam, the level of water to which it tends will be the same. If these data (first year) is compared with that obtained in the third year, it should be evident that the higher the initial level of the dam is, the greater the probability of getting higher levels.

Further, it should be affirmed that there is a 94% probability of reaching an appropriate level (of 3, 4, or 5 units of water). Specifically, there is a 84% probability associated with ending with 4 or 5 units of water. From these results, there is a 60% probability of reaching the maximum level allowed. On the other hand, the probability that the dam contains only 1 or 2 units of water is 1.94% and 3.88%, respectively. Thus, the probability of reaching minimum levels is less than 6%.

From these results, we can conclude that the dam level will be always above the minimum required, and that it will not suffer large fluctuations. Thus, the construction seems to be viable and to satisfy the irrigation scheme designed (as well as the consequent energy generation). Therefore, the impacts in local economy should be positive in terms of food security, economic activity, human well-being, and health. This result would be reached if the initial conditions are accomplished - in other words, if the probabilities related to the dam water contributions take place. Thus, an appropriate and rigorous study in this sense is relevant for the design of the project. Otherwise, a different region with, for example, different rain patterns (water contribution) could be selected.

Likewise, the tendency associated to the probability to reach the maximum level represents a risk of overflowing the dam. This is translated into the possibility to affect different areas and activities of the citizens, if it is not properly considered. In the same way, ecosystems would experience several negative impacts, both downstream and upstream.

Controlling the river flow of the Nile is a technical challenge with positive and negative impacts. Special attention should be given to further ones. If social losses are expected, trade-offs should be negotiated with the people involved. There is no doubt that this is a difficult process, but dialogue and negotiation, rather than imposition, should be the way. Similarly, a strategy of transparency should be applied to facilitate the involvement of all stakeholders. The positive impacts of encouraging participation can increase not only institutional trust but also build a more cohesive society, if seen from a long-term perspective. People's life style, cultural believes, traditions, and life environments are affected when constructing large-scale infrastructures like the studied dam. Thus, it should be mandatory, and even regularized, to integrate these aspects when implementing such projects.

Evaluation criteria

In order to evaluate this activity, a report will be requested from each group, in which the entire activity should be solved.

For the specific assessment of the report, we recommend using the rubric presented previously (see *Annex I*), and specifically, the technical aspects identified within the rubric. However, and depending on the responses of the students, aspects other than those included in the rubric should be considered. Thus, the rubric represents a possible instrument to facilitate the evaluation of the proposed activities as a whole. As mentioned above, the professor is free to choose an alternative method.

BIBLIOGRAPHY

African Economic Outlook. 2017. “Sudan 2017”. Available from: <http://www.africaneconomicoutlook.org/en/country-notes/sudan> [22 November 2017].

Dams Implementation Unit. 2007. Merowe Dam Project, Funding. Available from: <http://www.merowedam.gov.sd/en/funding.html> [27 November 2017].

Dirar, A., el Moghraby, A., Jalal Hashim, M., and Zeitoun, M. 2015. “Displacement and Resistance Induced by the Merowe Dam: the Influence of International Norms and Justice”. DEV Reports and Policy Paper Series. The School of International Development. University of East Anglia (United Kingdom).

Hildyard, N. 2008. “Neutral? Against what? Bystanders and Human Rights Abuses: The Case of Merowe Dam”. *Sudan Studies*, 37, 19-38.

United Nations. *Sustainable Development Goals: 17 Goals to Transform Our World.* Available from: <http://www.un.org/sustainabledevelopment> [20 November 2017].

United Nations, Department of Economic and Social Affairs, Population Division (UN-DESA). 2017. *World Population Prospects: The 2017 Revision*, custom data acquired via website. Available from: <https://esa.un.org/unpd/wpp/DataQuery> [20 November 2017].

United Nations Development Programme. 2016. *Human Development Report 2016: Human Development for Everyone*. New York.

UN-Water. 2016. *Water and Sanitation Interlinkages across the 2030 Agenda for Sustainable Development.* Geneva.

Verhoeven, H. 2012a. “Water, Civilisation and Power: Sudan's Hydropolitical Economy and the Al-Ingaz Revolution”. Department of Politics & International Relations. Oxford University. Oxford.

Verhoeven, H. 2012b. “Big is beautiful: Megadams, African water security, and China’s role in the new global political economy”. Available from: <http://oucan.politics.ox.ac.uk/index.php/blog/14059-big-is-beautiful-megadams-african-water-security-and-chinas-role-in-the-new-global-political-economy> [22 November 2017].

Verhoeven, Harry (2011). “Black Gold for Blue Gold? Sudan's Oil, Ethiopia's Water, and Regional Integration”. Briefing paper. London.

World Commission on Environment and Development. 1987. *Our Common Future*. Oxford

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