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The significance and impacts of large investments over the determination of irrigated agricultural land use: The case of the Euphrates & Tigris River Basin☆

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ABSTRACT

During the construction and especially water filling periods of Keban and Atatürk dams in the Euphrates River Basin, there have been a series of high level political tensions among Turkey, Syria, and Iraq for the allocation of trans-boundary water resources. It has been claimed that those large investments not only contribute to those investing countries but also to those affected ones. This research measures the contributions and impacts of major investments on the basin to the riparian countries. And how spatial land use decisions on irrigated agricultural areas in rival basin countries are made by means of optimization techniques. The model application is based on *with* and *without* analyses for the selected group of dams, which are Keban, Karakaya, Atatürk, Ilısu, Tabqa, Haditha, and Mosul dams, Habbaniye Reservoir, and Urfa Tunnels. The mixed integer programming (MIP) based on the Inter Temporal Euphrates and Tigris River Basin Model (ITETRBM) is used as an optimization tool for the necessary analysis. The impacts are presented by countries and by the generated economic benefits, water withdrawals, coverage areas of irrigated agricultural land, cities feasibly supplied from the reservoirs. The results have shown that large reservoirs in Turkey provide extensive contribution to the basin countries especially during drought periods when all major reservoir investments are considered together. That can be considered as potential for coalition during drought periods instead of competition.

Introduction

The Euphrates is the longest river in the Middle East Region and is heavily fed from the precipitations in Turkey (89%). After Turkey the river flows sequentially into Syria, and Iraq. Iraq does not have any contribution, and Syria contributes only remaining 11%. The second river in the region is the Tigris River, which, again, emerges in Turkey with a contribution more than half of its flow (51%). The Tigris River makes a 32 km border between Turkey and Syria. Iraq's contribution to the river is 39% of flow and remaining 10% is from Iran (Kaya, 2009). At Shatt Al-Arab both the Euphrates and the Tigris confluence and make a 81.9 Bm^3 average river flow in the region (Kolars, 1994).

Optimization techniques introduced into water resources allocation models by Flinn and Guise (1970), Vaux and Howitt (1984), and Booker and Young (1994). Game theory concepts added into trans-boundary water resource allocation studies by Rogers (1969, 1993), and Dinar and Wolf (1994). Both optimization and game theory methods have been utilized in the context of the Euphrates and Tigris basin by Kucukmehmetoglu since 2002. Later on, a series of extensions are provided by Kucukmehmetoglu and Guldmann (2004, 2010), Kucukmehmetoglu (2009, 2010, 2012), Kucukmehmetoglu and Geymen (2012a, 2012b, 2013), and Kucukmehmetoglu et al. (2010). The *first* publication (Kucukmehmetoglu and Guldmann, 2004) is on the game theoretic applications of the Euphrates and Tigris River Basin Model (ETRBM) for the allocation of scarce water resources. The *second* publication is based on inter-temporal extension of the model that the number of periods is increased from 1 to 2 (Kucukmehmetoglu, 2009). In this way, the model is improved to measure the impacts of reservoirs for seasonal and monthly inter-temporal allocations. The *third* publication is on the generation of three-party Pareto frontier surfaces and searches for an admissible allocation from this surface regarding the political nature of

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the system (Kucukmehmetoglu and Guldmann, 2010). The *fourth* extension is application of fuzzy logic and game theoretic principles in the resources allocation process regarding its highly political nature (Kucukmehmetoglu et al., 2010). The *fifth* extension is about the use of game theoretic principles for the generated Pareto frontier surfaces to attain rational and workable extend of tradeoff surface. The *sixth* extension is on the improvement in the database that agricultural demand nodes as decision making units (DMU) are spatially identified (by Geographic Information System – GIS) with its distance and relative elevation differences to the reservoirs (by Digital Elevation Model – DEM) for optimal allocation of resources (Kucukmehmetoglu and Geymen, 2011, 2012a, 2012b). The *last* extension, which is the content of this research, on the valuation of water holding capacities (dams and their reservoirs) of the basin countries (Kucukmehmetoglu and Geymen, 2013). Although all the earlier models are designed for a various political and rational aspect of allocation problems, this research specifically dwells on the spatial impacts of reservoirs on determining land uses for irrigated or dry farms.

During the construction, especially for the duration of water filling periods of major dams (year 1974–76 Keban and Tabqa Dams; year 1991 Atatürk Dam) in the upstream Euphrates Basin, a series of high level political tensions arose regarding trans-boundary water resources allocation issues among Turkey, Syria, and Iraq (Scheumann, 1998). It has been claimed that there are significant contributions of those large investments not only to those investing countries but also to those affected countries. This research measures the contributions and impacts of major investments to the riparian countries over the agricultural and urban areas. These contributions are clearly presented over the irrigable lands by means of rationally (optimally) irrigated agricultural zones. In other words, land uses decisions (irrigated versus not irrigated) are clearly illustrated by the spatially identified database in GIS. The model application is based on *with* and *without* analyses for the selected group of dams, which are upstream Keban, Karakaya, Atatürk, and Ilısu dams and Urfa Tunnels, downstream Tabqa (Ath Thawra), Haditha (Al Qudisiyah) dams, Habbaniye Reservoirs, and Mosul Dam.

The research content and hypotheses of the study can be summarized as follows:

- Whether the introduced MIP based the ITETRBM is a useful modeling tool to allocate scarce water resources for energy generation, urban demands, and agricultural lands.
- In the same way, whether, the ITETRBM is an effective tool to evaluate various basin-wide investment and policy decisions, such as availability or absence of reservoirs.
- In an optimal resource allocation perspective (maximizing net economic benefits in the basin), whether upstream and downstream reservoirs create needed and/or excessive capacities and their absences and availabilities provide varying benefits and/or costs to basin and countries.
- During multi-year droughts, whether the upstream reservoirs create significant positive side effects and increase coalition possibilities.

Model

Because this research is an extended version of Kucukmehmetoglu and Geymen (2012b) in terms of a series of sensitivity analyses measuring the impacts of large investments via with/without analyses, the used mathematical model is basically the same as the model used in Kucukmehmetoglu and Geymen (2012b). The mixed integer programming (MIP) based on the Inter Temporal Euphrates and Tigris River Basin Model (ITETRBM) is used as an optimization tool for the necessary analysis (Kucukmehmetoglu and Geymen, 2012b). The initial version of the Model is developed by Kucukmehmetoglu (2002) as Euphrates and Tigris River Basin Model (ETRBM) and then it is modified into an inter-temporal model (Kucukmehmetoglu, 2009) enabling wide variety of policy and sensitivity analyses. Since then, the model details and structure are improved significantly in *two directions* (Kucukmehmetoglu and Geymen, 2012b): The *first* irrigable agricultural lands are spatially identified via GIS, and then these lands are integrated into the model with their coordinates and elevations via DEM database. All irrigable lands are redefined as $10 \times 10\,\text{km}^2$ pixels i.e. decision making units (DMUs). Each DMU has a unique *distance* and *elevation* difference to nearby reservoirs. This update enabled the model to differentiate *gravity* and *pumped* flows. Due to technical limitations, the earlier models (Kucukmehmetoglu, 2002–2012) were based on the shortest distance between reservoirs and irrigation districts. However, with the spatially identified (with coordinates and elevation) DMUs, the updated ITETRBM opens a very practical research avenue to build advanced simulation and sensitivity studies regarding the availability and varying values of various basin-wide system parameters, human and land resource details, and political decisions (for the basin or beyond the basin). The graphical presentation capability via GIS is far beyond the earlier modeling practices and is open to further improvements. The *second* direction is the use of mixed integer programming (MIP) in designing and solving the ITETRBM. The used MIP technically enables to determine the optimal allocation of water resources for the entire DMUs (including agricultural and urban) in the Euphrates and the Tigris River Basin. The better the data base the more efficient the allocation of scarce water resources and optimal spatial decision making. The General Algebraic Modeling System (GAMS) is the software that is used to solve optimization problems. In GAMS the preferred solver is the COINCBC (acronym used in GAMS software) i.e. the COIN Branch and Cut solver (CBC) for Mixed Integer Programming problems. The MIP optimization results are visually presented by GIS.

In the next section the *network* and the *mathematical* content of the model is presented. The content is based on the same mathematical concept of the earlier publications; however, the difference comes from the way the analyses are pursued by the use of this model. This research aims at measuring the impacts of reservoirs to the basin countries via the ITETRBM.

Network structure of the ITETRBM

As presented in Kucukmehmetoglu and Geymen (2012b), the current ITETRBM contains 46 demand (i) and 1499 (maximum $10 \times 10\,\text{km}^2$ size) supply (j) nodes, and 3 inter-basin links from the Tigris to the Euphrates (Fig. 1). The three inter-basin links are identified with their supply node codes and directions as $j = 28 \rightarrow j = 14$ and $j = 31 \rightarrow j = 16$ in Iraq, and $j = 21 \rightarrow j = 12$ from Turkey to Syria. The one before *Shatt Al-Arab* ($j = 31 \rightarrow j = 16$), *Thartar Canal*, has already built, but the other two are, currently, only mentioned in the literature by Bilen (1994). Among 1463 agricultural demand nodes, 377, 354, and 732 DMUs are in Turkey, Syria, and Iraq, and covers approximate 1.99, 2.03, 4.36 million ha irrigable agricultural land, respectively. These DMUs are designed for irrigable lands (gray pixels: ▢) and non-irrigable dry farms are excluded from the optimization model. The major basin cities are designed as urban demand nodes (●). Similarly, among the 26 urban demand nodes, 18, 8, and 10 are in Turkey, Syria, and Iraq, respectively. In the same way, 16, 7, and 23 water reservoirs are assigned to Turkey, Syria, and Iraq, respectively. The supply node $j = 45$ stands for the *Persian Gulf*. The inter-temporal setting of the ITETRBM consists of 12

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