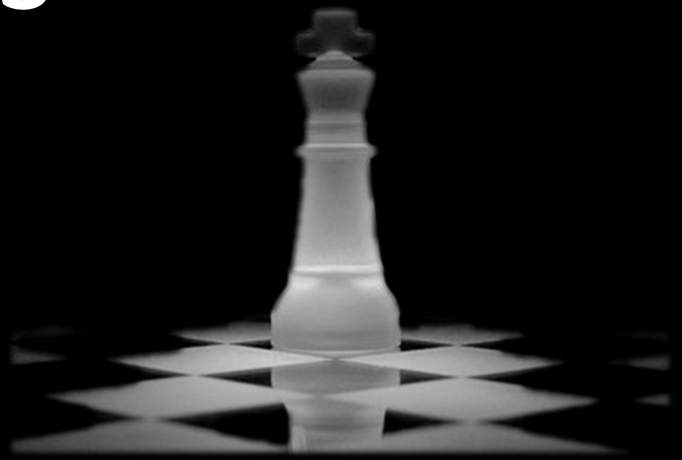
IRLA 2014 International Symposium | 26-28 November 2014 Patras, Greece
The Effects of Irrigation and Drainage on Rural and Urban Landscapes

ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ
UNIVERSITY OF PATRAS
Department of Civil Engineering

Evolution of game theory application in irrigation systems



Marianthi V. Podimata , PhD Student
Panayotis C. Yannopoulos , Professor

Ancient river valley civilizations

For any civilization to grow and succeed, water availability and supply is a prerequisite.

Irrigation: sharing a body of water, for agricultural purposes dates from the time of first land-holding farmers.

THE FIRST RECORDED IRRIGATION DISPUTE

Dispute between the cities of Umma and Lagash over irrigation systems and diversion of water from Tigris and Euphrates rivers (from 2500 to 2400 BC). Continuing conflicts over Mesopotamia led Hammurabi in 1790 B.C. to enforce laws prohibiting water theft in irrigation systems, in his famous 'Hammurabi's Code' (Hatami and Gleick, 1994).

Rivalry = from sharing to conflict

rivus + -alis

stream of the kind of

Rivalry = from sharing to conflict

19th century

USA (Eastern California)

- The construction of an aqueduct that diverted water from the Owens River Valley to Los Angeles led to farmers' rebelling. The L.A. City purchased private land holdings and water rights of farmers in Owens Valley. Agriculture interests in the valley were stopped (Reisner, 1993).

20th century

Middle East (Jordan, Syria, Israel)

- War broke out about the waters of Jordan River shared by Jordan, Syria and Israel, in the 1950's and 1960's (Kliot, 1994)[10]. These military actions contributed to the tension that led to the 1967 Arab-Israeli War (Gleick et al., 1994).

21th century

Africa (Ethiopia)

- During the drought of 2004-2006, there was significant fighting over water wells between local pastoral farmers and herders called "well warlords" and "well warriors". The extensive fighting, known as the "War of the Well," left over 250 dead and many injured (Kreamer, 2012).

Irrigation conflicts

California water conflict

Times

THURSDAY, NOVEMBER 6, 1913—EDITORIAL SECTION

GLORIOUS MOUNTAIN RIVER NOW FLOWS TO LOS ANGELES' GATE

OS ANGELES INVESTMENT COMPANY INVESTIGATED.

Federal Authorities Act Under Orders from Washington Chiefs.

'THE INYO REGISTER' AND 'THE OWENS VALLEY HERA

SUPPLEMENT NUMBER ONE.

BISHOP, INYO COUNTY, CALIFORNIA, JANUARY 7, 1913.

GREED OF CITY RUINS THE OWENS VALL

STATE-WIDE INTEREST RISES OVER OWENS VALLEY FIGHT

SHE FACES LIFE ALONE; MATE GONE

LOSS OF BUSINESS AND PREST HAS COME TO CITY'S VE

Water wars in Middle East

Day 1

The Washington Post
Times Herald
JUNE 6, 1967
10c
Israel Claims Major Land, Air Gains;
Hope for U.S.-Soviet Agreement Rises

Day 2

The Washington Post
Times Herald
WEDNESDAY, JUNE 7, 1967
10c
Israel Pushes On; U.N. Votes for Truce;
6 Arab States Cut U.S. Ties; Suez Shut

Day 3

The Washington Post
Times Herald
THURSDAY, JUNE 8, 1967
10c
Israel Routs Arabs, Frees Gulf;
Truce in Jordan; Egypt Defiant

Day 4

The Washington Post
Times Herald
FRIDAY, JUNE 9, 1967
10c
Egypt, Syria Accept Cease-Fire;
Israel Hits U.S. Ship, 10 Killed

Day 5

The Washington Post
Times Herald
SUNDAY, JUNE 11, 1967
25c
Foes Heed Cease-Fire, Halting the War;
Russia Cuts Israel Ties; Nasser Back In

Day 6

The New York Times
VOL. CXVI....No. 39,950
NEW YORK, SUNDAY, JUNE 11, 1967
35 CENTS
LINDSAY VETOES BUDGET CHANGES; CHARGES POLITICS
Rejects Cuts and Additions
To Our Readers
U.S. PLANES BOMB A PLANT IN HANOI; ONE JET DOWNED
First Raids on Capital in 3
CEASE-FIRE IN SYRIA ACCEPTED; ISRAELIS HOLD BORDER HEIGHTS; SOVIET BREAKS TIES TO ISRAEL

Dying for Water in Somali

www.washingtonpost.com/wp-dyn/content/article/2006/04/13/AR2006041302116.html

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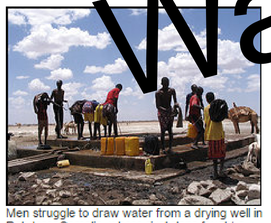
WORLD

In the News RGIII Thanksgiving storm Ruth Bader Ginsburg Ferguson Cleveland shooting

washingtonpost.com > World > Africa

Dying for Water in Somalia's Drought

By Emily Wax
Washington Post Foreign Service
Friday, April 14, 2006



Men struggle to draw water from a drying well in Rabdore, Somalia, where rival clans fought a two-year war over the water supply. (By Emily Wax -- The Washington Post)

RABDORE, Somalia -- Villagers call it the "War of the Well," a battle that erupted between two clans over control of a watering hole in this dusty, drought-stricken trading town.

By the time it ended two years later, 250 men were dead. Now there are well widows, well warlords and well warriors.

"We call them the 'warlords of water,' " Fatuma Ali Mahmood, 35, said in a raspy voice about the armed men who control access to water sources.

One day last year, Mahmood's husband went out in search of water. Two days later, he was found dead, she said as an infant on her back cried and nine other children tugged at her torn dress. He was shot when an angry crowd began fighting over the well, she said.

"His body was bloodied, swollen and just lying there with the other dead by the well, left in disgrace. The shame. We'd never seen conflict at this level of violence," she explained, shielding her eyes from a dust storm that was swirling in the heat under a blue sky. "Thirst forces men to this horror of war."

In Somalia, a well is as precious as a town bank, controlled by warlords and guarded with weapons. During the region's relentless three-year drought, water has become a resource worth fighting and dying over.

The drought has affected an estimated 11 million people across East Africa and killed large numbers of livestock, leaving carcasses of cows, goats and even hearty camels rotting in the sun. The governments of Kenya and Ethiopia have mediated dozens of conflicts over water in their countries, even sending in police and the army to quell disputes around wells.

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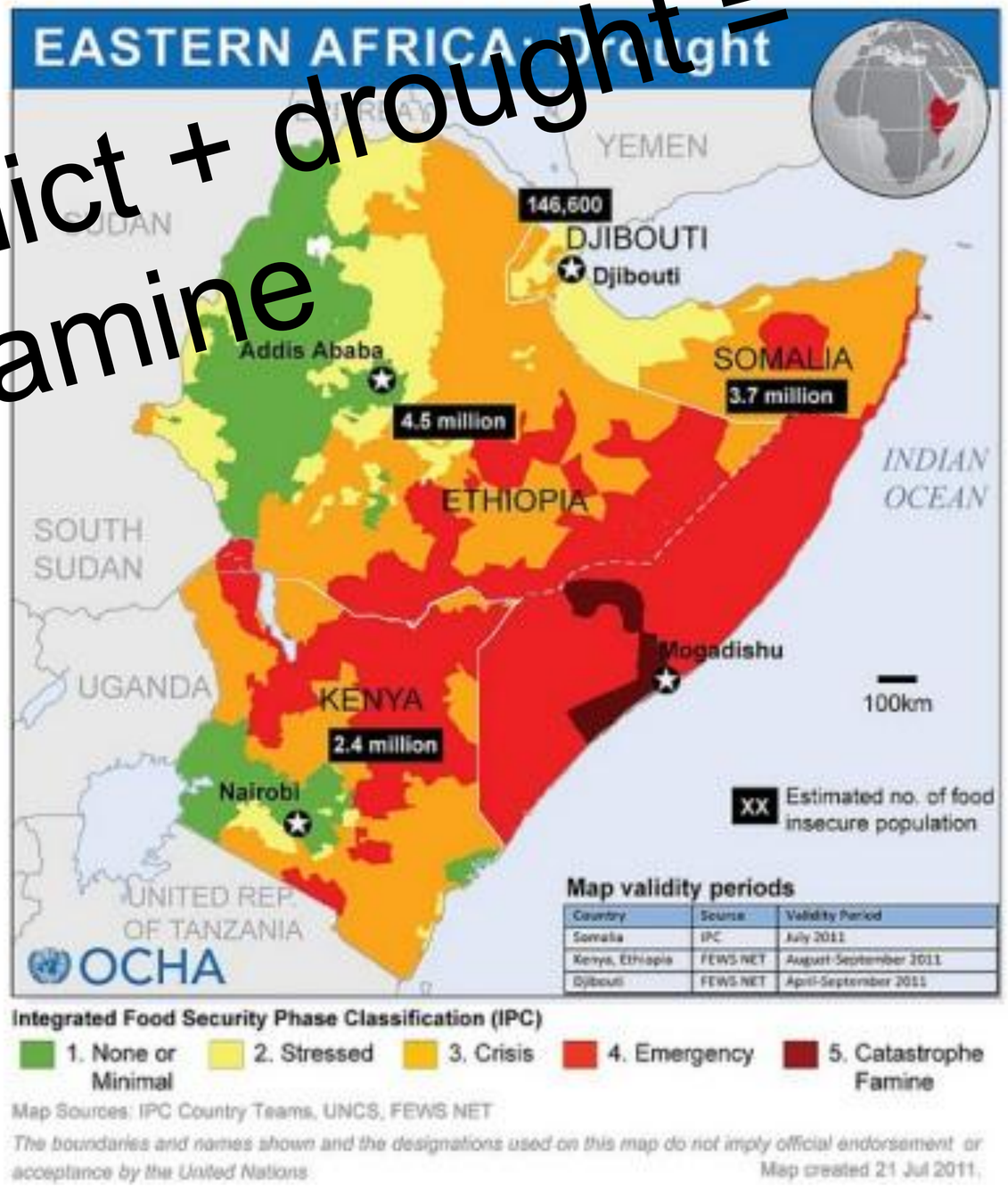
Water conflict + drought = famine



Game Theory & Irrigation

competition

cooperation

in water use for irrigation purposes

Game Theory

What is exactly game theory?

A mathematical method of problem analysis and decision making in strategic interaction

Where can we find applications?

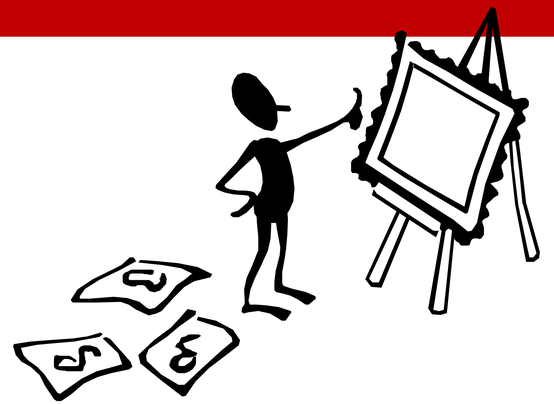
Applications in economics, political science, computer science, resources management, etc.

What about water?

Water quantity and quality management, water allocation, water sharing, water diplomacy, etc.

Game Theory

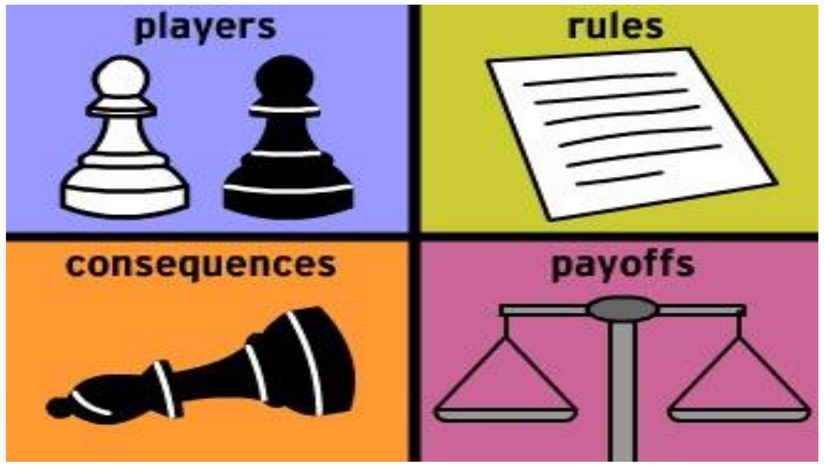
Basics



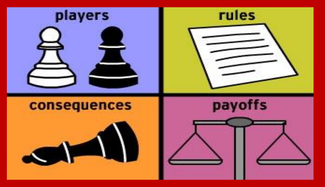
- Four elements to describe a game:
  - **players**: decision makers
  - **rules**: when each player moves, what are the possible moves, what is known to each player before moving
  - **consequences** (define strategies): outcomes of the moves
  - **payoffs** of each possible outcome

$$G \triangleq \langle N, (S_i), u_i \rangle$$

G =Game
N =Players
S =Strategies
u =Outcomes



Game Theory



Taxonomy

- Non-cooperative
- Cooperative
- Zero-sum
- Non-zero sum
- Static
- Dynamic
- Perfect information
- Imperfect information
- Bayesian
- Stochastic
- Fuzzy
- Differential
- Metagames

Famous Games

What about irrigation water ?

Game Theory & Irrigation

Pumping groundwater game

$$G = \langle N, (S_i), u_i \rangle$$

$$N = 2$$
$$S_1 = S_2 = \{PRL, PRH\}$$
$$u_1 = u_2 = \{1, 2, 3, 4\}$$

		Farmer 2	
		PRL	PRH
Farmer 1	PRL	3 / 3	1 / 4
	PRH	4 / 1	2 / 2

PRL = Pumping Rate Low

PRH = Pumping Rate High

Game Theory & Irrigation

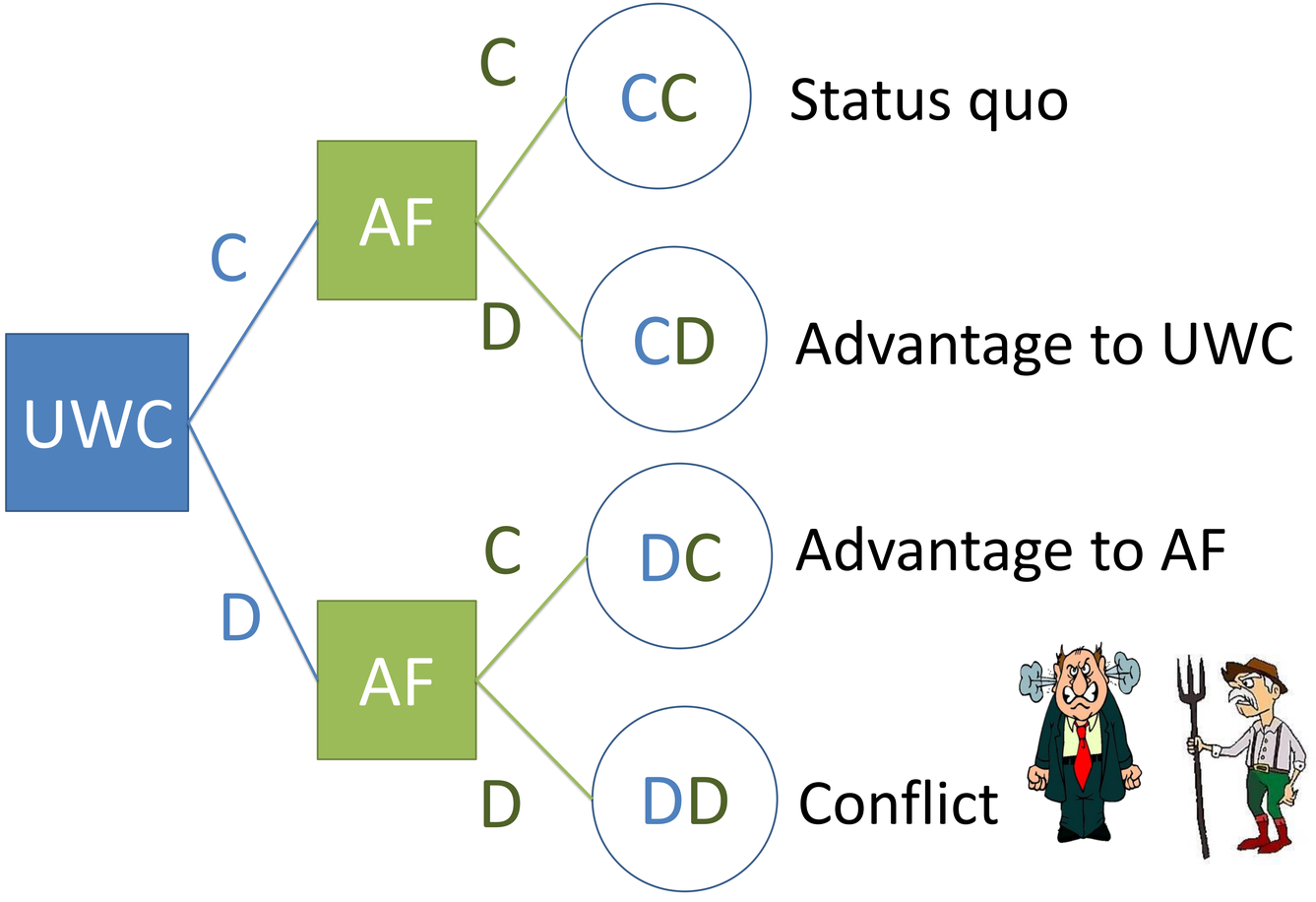
Water rights game

$$N = 2$$

$$S_1 = S_2 = \{C, D\}$$

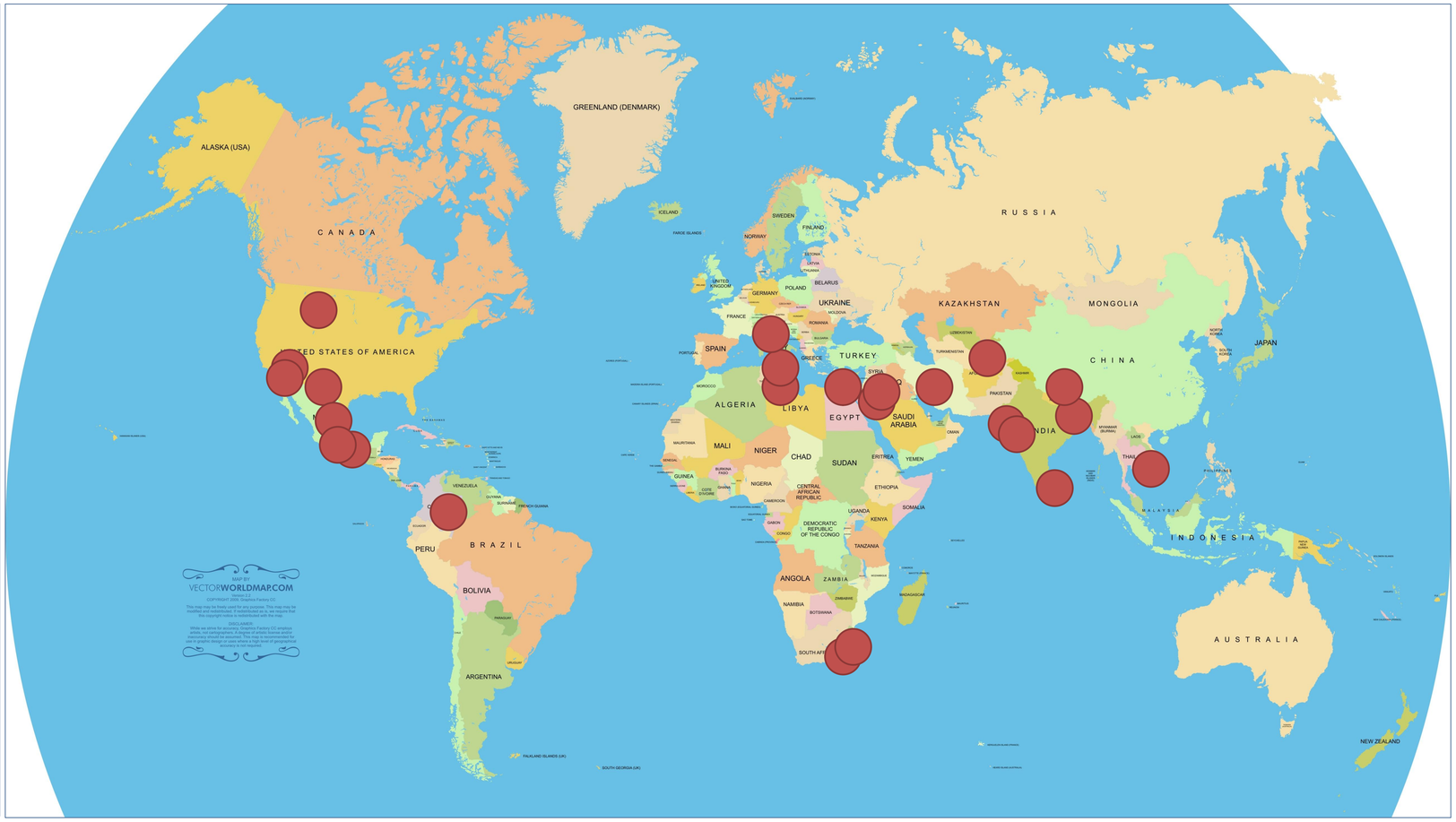
□ Decision node
○ Terminal node

AF: association of farmers
UWC: urban water company
C: cooperation
D: defect and challenge status quo



Game Theory & Irrigation

Literature review



Game Theory & Irrigation

Rogers
India & Pakistan disputes about the water of Ganges and Brahmaputra rivers that serve in irrigation (LP +GT)

1969

1976
Bogardi & Szidarovsky
the definition problem about the equilibrium on water volume for irrigation purposes among farmers in a rather qualitative perspective (oligopol game)

Gisser & Sanchez
the pumping water from a common aquifer (raised externalities) under no control (free marker) and optimal control by using deterministic equations

1980

1989
Negri
He reviewed the groundwater pumping model and examines the adopted pumping strategies in aquifer with restricted access by using differential open loop and feedback games

Yaron &Ratner
increasing use in irrigation of low quality water (with high salinity)/Quasi-empirical case in Israel (cooperative games)

1990

1991
Dixon
ground-water extraction and drainage water management (myopic, open-loop, conventional closed-loop and trigger strategy)

Weissing and Ostrom
how irrigation institutions affect the distribution of equilibrium outcomes of irrigators/ irrigation games without guard positions/ stealing concerning pumped water

Dinar et al.
cooperative GT over irrigation water under water scarcity and salinity

1992

1993
Ostrom &Gardner
asymmetries in irrigation systems between farmers located near the source of water (head-enders) and farmer placed in distance from it (tail-enders)

Xepapadeas
a quality-quantity groundwater problem in Crete (Greece) + regulatory framework (water tax) in achieving efficient water allocation under the specific water consumption conditions in the area

1996

Game Theory & Irrigation

2000

Dayton – Johnson
water and cost allocation arrangements under different distributive rules the determinants of cooperation in a farmer-managed irrigation system

Zorba et al.
Prisoner's Dilemma game and genetic algorithms are used as an optimization tool in order to maximize the number of farmers with increase in their income

2001

Sakurai & Palanisami
compared collective action in farming (tank irrigation) versus individual irrigation schemes (well irrigation) in India

2003

Faysse
best water allocation rule in farming when (i) farmers are autonomous in decision-making regarding irrigation and (ii) a manager impose some rules about the water distribution to farmers and the fee-payments

2004

Aadland &Kolpin
Cost-sharing rules over an irrigation ditch between head-enders and tail-enders

Just & Netanyahu
interconnected games with real case conflict situations between Israel and Palestine, in order to examine negotiation feasibilities and infeasibilities

2006

Dinar et al.
water allocation decisions as a cooperative game in irrigated land of Kat River Basin in South Africa

2007

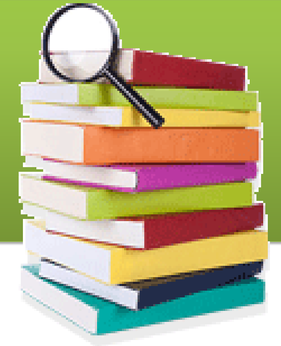
Désolé
Based on results of Dinar et al. (2006), a similar comparison RPG vs CGT

Salazar et al
a conflict resolution method applied to an irrigation district in Mexico (regarding over-pumping and the potential environmental risk) by using 4 different method solutions under different cropping patterns and chemical loading

2010

Kerachian et al.
sequential bargaining games & arising conflicts among water users and water agencies in Iran.

Game Theory & Irrigation



2010

Madani

addresses several types of (and reasons for) conflicts over water issues and reviews applicability of game theory to conflict resolution by presenting simple water resource non-cooperative games

2011

Janssen et al.

asymmetries in strategies between head-enders and tail-enders in irrigation systems & dilemma of farmers regarding how much to invest in construction of shared infrastructure for irrigation purposes

2012

Janssen et al.

how cooperation among farmers evolve when head-enders and tail-enders face asymmetric dilemmas / Fair water allocation in farming under different allocation rules

Yamamoto et al.

simple GT (Prisoner's dilemma) to a water-shaving project (drip irrigation) in Tarim River Basin, China (he cost of work and maintenance in this project, water-fee reductions after the introduction of water-shaving irrigation and yield benefits)

Sechi et al.

water cost allocation arrangements in among competitive water requests for irrigation &civil/industrial use (application in Sardinia, Italy under a cooperative GT approach)

Zaikin & Arredond

an experiment (non-cooperative game) under with farmers from Uzbekistan (Dashtobod) in which water applied allocation norms embrace penalty and bonus rules

Finger & Borer

factors contributing to the continuation of traditional channel based irrigation systems in a rural area of Swiss territory

2013

Kimmich

associates groundwater irrigation with electricity policies for irrigation in India (Andhra Pradesh) and presents a situation of social learning depicted as a sequential nested coordination game

Roseta-Palma et al.

the problem of illegal groundwater pumping. They created a model of groundwater management that explicitly recognizes the existence of distinct groups of players (namely legal and illegal water users) and analyze adaptive behavior of irrigators under the supervision of a regulator/social planner that poses economic and social penalties to illegal users

2014

Msangi

discusses the learning behavior among farmer agents that pump from the same aquifer, in a non-cooperative manner, incorporating uncertainty (shochastic equations) about the levels of inflow into the aquifer system and examines how players adapt into new situations of competitive extraction (application in Kern County, California, USA)

today

Game Theory & Irrigation

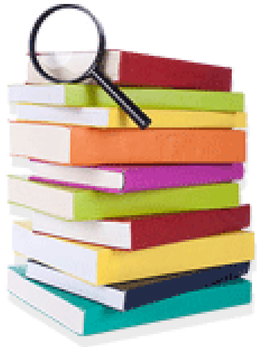
A transition of argued issues becomes apparent when the evolution of GT articles in literature (discussing matters over irrigation water) is studied.

Premature works use more descriptive methods, but give less emphasis on environmental adverse effects of water overexploitation

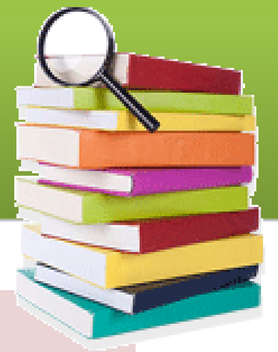
As environmental problems became more intense, researchers incorporated in their equation-models more environmental parameters

The discussion is focused on water allocation issues, given narrow water resources for irrigation purposes. This discussion is moved to cost allocation issues, under more sophisticated econometric analyses, in which the factor of uncertainty is investigated. Simultaneously, issues about the operation and management of self-organized irrigation systems and irrigation institutions become more open to debate

Last years, discussed conflicts over irrigation water are not limited to sharing of costs/benefits or management issues, but are extended to other social and political aspects of decision-making, like social learning and adaptive behavior of players



Game Theory & Irrigation

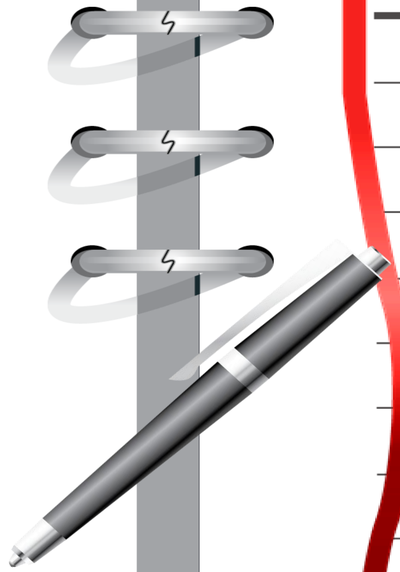


Subject issue	•The majority of works is focused more on over-pumping from aquifers and less on withdrawals from surface water
Location	•The majority of empirical cases and approaches are referred in developing countries, where access to water resources (in quantity and quality) is lacking or highly variable
Classification	•So far, literature addresses issues/conflicts regarding water/cost allocation, groundwater management, balancing water quality-quantity issues, institutional arrangements and social learning

Conclusions

By documenting articles in the literature on GT dealing with irrigation issues, we understand that there is a pluralism of addressed subjects regarding irrigation water

The utility of GT indicates its great potentials to understand complex problems about irrigation water and to improve agriculture governance



NOTES

GT applications address issues associated with the concept of:

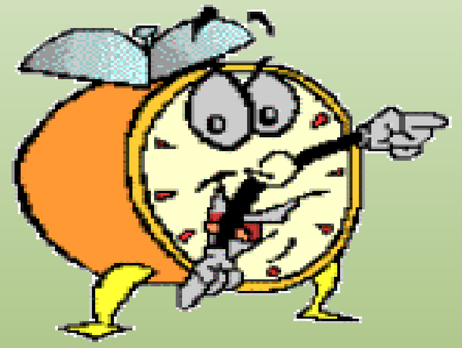
a) fair water allocation

b) balanced cost allocation among irrigators,

c) equilibriums on water withdrawals and environmental sustainability

d) balancing water quality-quantity issues

e) institutional arrangements



Thank you
for you attention