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Towards sustainable management of groundwater: A case study of semi-arid area, Iraqi Kurdistan region

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Abstract: In this paper, Erbil province the capital of Iraqi Kurdistan has been chosen as a representative case study for a large number of provinces in semi-arid areas, lacking imbalance between water demands and supply. Climate change is expected to bring adverse impact on water availability, which would intensify the pressure on water resources and increases the environmental concerns. Sustainable water use and prudent management prefer the rational water use and to preserve groundwater exploitation. The study aims to develop a framework considering sustainability aspects. A total of twenty wells have been selected among ninety-nine observation wells across the province along a period of 16 years from 2000 to 2015 to assess water level depression. The groundwater level had been falling nearly by half, this highlights the issues that the groundwater level has been significantly affected by impacts of the non-sensible usages of groundwater, dry spell periods, mismanagement of water resources, and unsustainable planning. Urban areas and suburbs were more exposed to water insecure than outskirts The results also suggest that the management of water resources and drainage systems would get worse if there was not adoption on a clear policy to manage it by relying on a robust framework based on sustainability concepts.

Key words: Groundwater depletion; Sustainability; Water management; Climate change; Framework

1. INTRODUCTION

Groundwater has a substantial role in agriculture, water supply and health, and the elimination of poverty in both urban and rural areas, thus, it is regarded as a vital and the sole resource in most of the studied semi-arid regions. Currently, Iraq is dramatically disturbed by complex political and socio-economic problems. In its northern part, i.e. the Kurdish-inhabited region, fast urbanization and economic expansion are visible everywhere. Monitoring and water management schemes are necessary to prevent aquifer over-exploitation in the region. Artificial recharges with temporary runoff water, construction of subsurface dams and several other aquifer management and regulation measures have been designed, and some implemented, in order to improve the water situation (Stevanovic and Iurkiewicz, 2009).

Recently, the World Economic Forum 2017 within its global risk report has pointed out that Environment-related risks also stand out in this year's global risk landscape. The major risk interconnections of Global Risks Perception Survey (GRPS) involve environmental risks, the most frequently cited of these being the pairing of "water crises" as well as "failures to climate change mitigation and adaptation". The World Bank expects that water stress could cause extreme societal overstrain in regions like the Middle East, where the economic effects of water scarcity could reach at risk 6% of gross Domestic Product (GDP) by 2050 (Heijden et al., 2015).

Population growth associated with accelerated social and economic activities and developments as well as expanding irrigated areas for agriculture purposes are main drivers for an ever-increasing demand for water worldwide (Wada et al., 2010). On the other hand, climate change has put additional pressure on water resources in arid and semiarid areas, which are naturally facing water shortages. Dragoni and Sukhija (2008) have pointed out the importance of understanding the impact of climate change and variability on the availability and sustainability of surface and groundwater resources. The need and the necessity for groundwater studies in water-scarce areas are crucial for sustainable management of water resources. Warner (2007) has underlined that there is a need to asses and understand climatic change and variability over long periods of time to better plan and manage groundwater resources, while taking into account the increasing pressures on groundwater resources due to population growth, industrial, agricultural, and ecological needs.

Furthermore, literatures indicated that research has started to focus more on understanding the impacts of climate variability and alteration on groundwater quantity and quality, these impacts remain poorly understood (Green et al., 2007). Groundwater-residence time scales can range from days to tens of thousands of years or more, which delays and disperses the effects of climate and challenges efforts to detect responses in the groundwater to climate variability (Chen et al., 2004). Moreover, human activities, such as groundwater pumping and resulting loss of storage and capture of natural discharge, are often on the same time scale as some climate variability and change scenarios, which makes it difficult to distinguish between human and climatic stresses on groundwater (Hanson et al., 2004). Therefore, the need and the necessity for groundwater studies in semiarid areas are considered as a mainstay of sustainable water management, as it has always taken into account as one of water resources that ought to be reliable and supportive for surface water resources in the purpose of agricultural irrigation uses, livestock's watering, and domestic water supplies in developing countries.

1.1 Groundwater depletion

Famiglietti (2014) have said that "Groundwater depletion the world over poses a far greater threat to global water security than is currently acknowledged", therefore, semi-arid regions as part of the global scale are also threatened by the diminution of groundwater availability.

In areas that are exposed to water shortages, and that have large groundwater aquifer; the groundwater is often used as an alternative source of water supply. Groundwater overuse or continuing depletion occurs, whenever the abstractions of groundwater surpass its repletion (Wada et al., 2010).

The groundwater levels in the study area strongly declined in the drought period 2006-2009. Several sources in the area indicate that groundwater pumping in the study area intensified during the last years. It is likely that the total pumping rates exceed recharge rates over large areas, as groundwater tables are declining. Mulder (2013) says a negative residual term was found of about 10 mm per year.

The total global groundwater depletion is quite substantial, totalling an estimated 39 (±10) % of the global yearly groundwater abstraction, 2 (±0.6) % of the global yearly groundwater recharge, 0.8 (±0.1) % of the global yearly continental runoff and 0.4 (±0.06) % of the global yearly evaporation. This makes groundwater over-abstraction a term of the global water balance that cannot be neglected (Wada et al., 2010). Moreover, studies on semiarid regions have seen the semi-arid regions are not excluded while the crisis is being exacerbated by the over-demand for water. Continued groundwater depletion will be unsustainable, with potentially dire consequences for the economic and food security (Famiglietti et al., 2011). The global groundwater depletion has been increasing since the 1960 and is likely to increase further in the near future, while the increase of impoundment by dams has been tapering off since the 1990s (Chao et al., 2008).

1.2 Groundwater replenishment

Ebrahimi et al., (2016) have estimated that irrigation water has more contribution than rainwater to recharge the ground in arid and semi-arid areas by one-third. On the other hand, the groundwater can be recharged by municipal wastewater, but still there are some uncertainties in terms of health risk considerations, and have limited the use of reclaimed disposed urban wastewater for groundwater recharging. This is based on the groundwater recharge criteria.

1.3 Groundwater and surface water interaction in semiarid regions

The interactions between groundwater and surface water are complex. To understand these interactions in relation to climate, landform, geology, and biotic factors, a sound hydro-geo-ecological framework is needed. Surface-water and groundwater ecosystems are viewed as linked components of a hydrologic continuum leading to related sustainability issues. The mechanisms of interactions between groundwater and surface water (GW–SW) as they affect recharge–discharge processes are comprehensively to be understood, and also the ecological significance and the human impacts of such interactions.

Despite commendable efforts to craft solutions to meet required surface water allocations, consideration of the ability of groundwater withdrawals to meet current and future demands remain dormant. The heightened awareness of the rates of groundwater depletion will reinforce urgent discussion on conjunctive management solutions required to ensure a sustainable water future (Castle et al., 2014).

1.4 Sustainable management of groundwater

Sustainable groundwater use should be established by management institutions in concert with regional stakeholders, while taking into account hydrologic, environmental and political constraints. Multidisciplinary studies supported by reliable data and integrated water resources modelling are desired ends in the basin, but full integration of the disciplines must await future research (Al-Azawi and Ward, 2017).

Securing future groundwater availability involves a multi-spectrum of efforts, including minimising net losses from the underground reservoir, managing groundwater as an integrated part of the hydrologic cycle, developing infrastructure based on an understanding of the natural hydrologic system, using water wisely and efficiently, and allocating and monitoring water fairly for human as well as environmental and ecological needs (Sheng, 2013).

1.5 Climate change impact on groundwater resources

'Climate change is the most severe problem that we are facing today - more serious even than the threat of terrorism' said the UK government chief scientific adviser (King, 2004). Researchers have become convinced that water supplies forced by global climate model in semi-arid regions. Studies show that up to 60% of the climate-related trends of river discharge, winter air temperature, and snow-pack's during the second half of last century are human-induced. Water shortages, lack of storage capability to meet seasonally changing river flow, transfer of water from agriculture to urban uses, and other critical impacts of climate variations are expected (Sheng, 2013).

In arid and semiarid regions such as the study area, people live in drought most the time. In addition to impacts of groundwater pumping, a prolonged drought period can further lower groundwater level to the point at which shallow wells may go dry and it intensifies the issue much more.

2. MATERIALS AND METHODS

Groundwater water levels were observed at ninety-nine observation wells across the case study area. Data were made available by the Ministry of Agriculture and Water Resources in the Kurdistan Region of Iraq. Twenty observation wells have been chosen out of the total (i.e. ninety-nine). The selection was based on the availability of a complete set of monthly readings of water level between 2000 and 2015. The groundwater level observed in 2000 has considered as a reference level to examine the changes in water level observed in the investigated observation wells. Figure 1 shows boundary of the appointed observation wells across the study area.

Microsoft Excel (2010) has been used to prepare the tables and charts, also the trends of groundwater level, as well as ArcGIS v.10.2 has been used to make interpolations and spatially distribution of the data. The data were arranged and tabulated based on what have been collected and consisted of; well code and IDs, the district that the well situated, coordinates, well depth, geological formation, groundwater basin, and monthly readings of groundwater level. Monthly readings along the 16 years have been converted to mean annual readings, then the differences of the first and last readings were found to check whether been regressed or not.

3. RESULTS AND DISCUSSION

3.1. Groundwater data analysis

The data of groundwater levels have been managed as the time series along studied period versus the depression of water in the wells. The values of trends' slope has been calculated, based on this a spatial distribution map of groundwater depression has been prepared.

3.2. Results obtained from the groundwater study

Results show that the fall in groundwater level was between 11% and 88% with respect to the reference water level. The average fall was almost 42% and the standard deviation nearly 25%. This points out that the level of groundwater has been significantly decreased; this is because of the combined impact of the non-rational utilisation of groundwater, impacts of dry-spell periods (1999-2001 and 2007-2008), the lack of groundwater recharge, and mismanagement in surface-water and groundwater interactions.

Findings have also highlighted the future potential risk of the combined effect on irrigated agriculture areas, livestock's watering, as well as domestic water supply. Moreover, the notable drop observed in groundwater level between 2000 and 2015 has underlined that the ground water level at some sites has reached a critical level indicating that the utilisation of groundwater has to be carefully treated and sustainably managed. The preliminary results are in line with what has been stated in the report of (Dizayee and Johnson 2016) that the present exploitations of groundwater in the Erbil basin is unsustainable and a significant attention should be paid to the sustainable use of groundwater and the necessity of healthy management of groundwater.

A spatial distribution map has been prepared (Figure 1), this has been set based on the regression slope (b-value) trends for the selected observation wells. The regression values give a general indication that the groundwater level in all wells have significantly dropped, the values of declination ranged from 0.05 to 5.8, by focusing on this map, it can be perceived the that urban and suburban areas were most affected than peri-urbans.

From what has been reviewed and studied, a schematic diagram (Figure 2) has been developed demonstrating the main drivers that cause a serious degradation in groundwater levels in arid and semi-arid areas. Overexploitation of groundwater, population growth associated with a notable increase in water demands, and climate change and variability contribute significantly to groundwater decline. Illegal abstraction of groundwater, weakness in application of existing regulations and legislations, and delay in updating the current regulations and legislations are the main features of the non-rational utilisation of groundwater. Reduction in annual precipitation, increase in temperature and evapotranspiration rates and successive droughts have increased the dependency on groundwater, particularly in areas where there is a shortage in surface water. The fall in the annual amount of precipitation decreases groundwater aquifer replenishment, resulting in decreasing groundwater levels as the withdrawal rate exceeds recharge. Major uncertainty still surrounds the detailed effects of climate change on groundwater replenishment. This may attribute to the limited research on the impacts of climate change on groundwater.

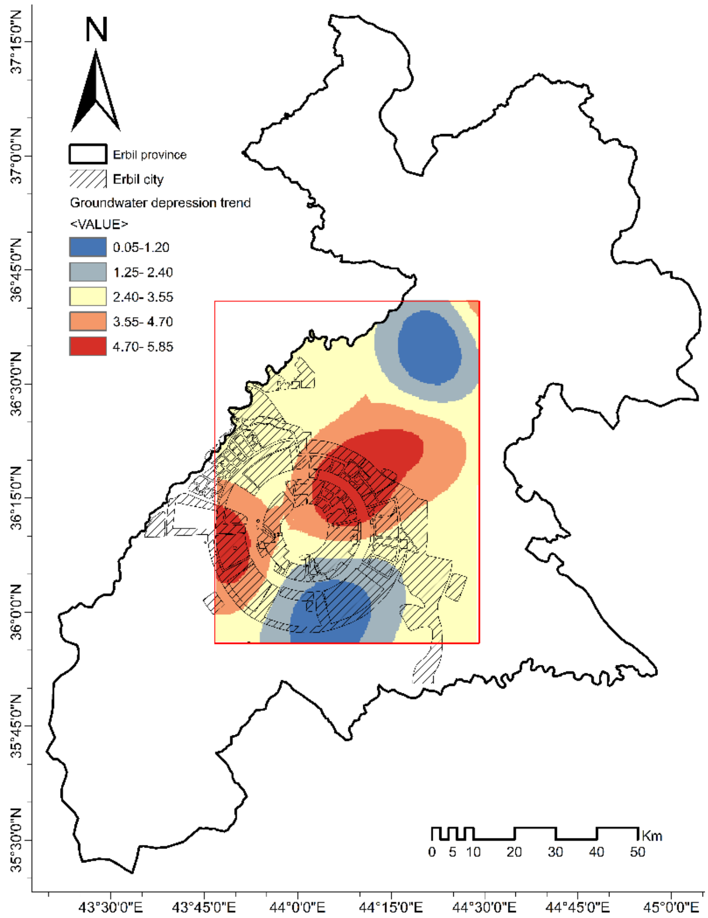

Figure 1. The depression trend in the selected twenty observation wells

Despite that the study area is characterised by highly infiltrative and karstified ground, the water levels of the aquifers in Northern Iraq are very responsive to changes in rainfall regimes (Mulder 2013), but the direct effect of climate change on groundwater resources depends upon the change in the volume and distribution of groundwater recharge. Less precipitation in winters and warmer summers lead to notable deficits in groundwater recharge. However, aquifers are recharged more effectively by prolonged steady rain, which continues into the spring, rather than short periods of intense rainfall (Groundwateruk, 2016).

The effects of climate change on groundwater across Erbil province include: (a) a long-term decline in groundwater storage, and (b) increased frequency and severity of groundwater droughts. These effects critically have impacts on; the socio-economic conditions of the local communities, groundwater-related impacts on water supplies, livestock's watering, and on ecosystems that depend on groundwater such as wetlands, ecosystems in streams fed by groundwater, hanging valleys and swamps, limestone cave systems, and springs.

4. CONCLUSIONS

This study seeks to help the stakeholders as planners, decision-makers, and community's by developing a framework to tackle the problems that these areas have been encountering in groundwater depletion. The study has adopted an approach whereby initiating from specific elements and induced toward the thorough form of the framework, which highlighted a number of aspects; sustainability; regulations and legislations pertaining the sustainable water management; socio-economics situation; climate change; and eco-system issues, which are derived from the themes that have become concerned by hydro-policy-makers and who interested in sustainable drainage systems. The shortage is coming from over-abstraction of the groundwater, poor-management of water resources, population growth, and increase in global temperature.

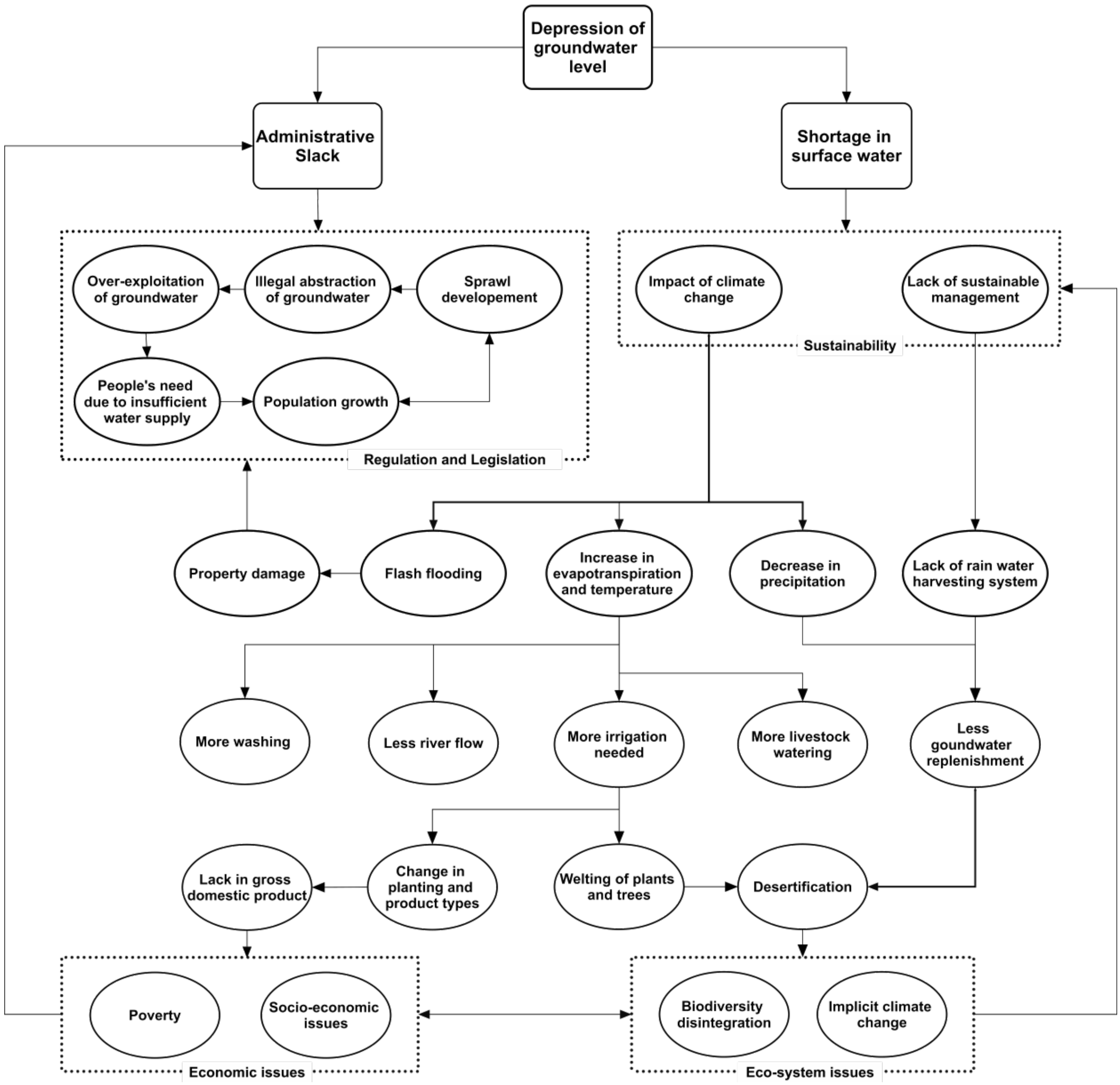

Figure 2. A schematic diagram of interrelated aspects within a framework for sustainable groundwater management

Urban and suburb developments are the most affected areas than peri-urbans and outskirts, which need an official posture toward the retrogressive situation. The necessity of mighty management of groundwater is essential through sustainable use of groundwater. The semi-arid regions are most vulnerable to groundwater depletion due to the intensified stress on water demand for multi purposes, this because of the lack of legislations, recurring drought periods, living levels, and non-sustainable strategies.

Understanding the potential effects of climate variability, as well as repletion situation on groundwater availability and quality, is more complex than with surface water, and needs more comprehensive studies. Therefore, there is a need to develop a robust framework that should be based on sustainability concepts to manage water resources and drainage systems as an interrelated components for maintained groundwater.

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