Reviewing Irrigation Water Scarcity And Sufficiency With A Case Study Of Jhikhukhola Watershed, Nepal

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Abstract: Water scarcity is rapidly growing issue especially in water scarcity country. Projected population is a considerable factor in water scarcity because crop production is more in irrigated agriculture than rain-fed agriculture but only about 20 % agricultural land is facilitated by irrigation in the world. Rice is a main food grain in more than half the population in the world including in Nepal. Thus, rice production is an important crop as a food and economic growth of the country. The irrigation water is declined continuously every year due to rapidly increase in population growth, urbanization, depleting groundwater, high water demanding crop and inefficient irrigation for rice based farming which make a problem in self-sufficiency in food. "Jhikhukhola" is only one river in Panchkhal valley in Nepal is important river because of Jhikhukhola watershed (panchkhal valley) is economically very active in terms of agriculture, as most of the land in the watershed is covered by crop production. But nowadays, it is badly facing water scarcity in irrigation; so, different types of options of the technology to improve the water sufficiency in the Jhikhukhola watershed have been studied.

Keywords: Water scarcity in irrigation, Water sufficiency in irrigation, Jhikukhola river, Panchkhal valley

1. Introduction

Resources of water are renewable and non-renewable; and groundwater and surface water. The water flow in rivers is simply considered as renewable water resources, whereas deep aquifers which have a significant no replenishment rate; is non-renewable water resources. Similarly, water resources are blue water i.e. water above and below the ground (rivers, lakes, groundwater) and green water i.e. water contained in the soil in the unsaturated zone that is directly used and evaporated by rain fed agriculture. Thus, green water flow has two components as productive part (transpiration) involved in biomass production and the non-productive part (evaporation) [1]. The total freshwater resources in the world in 2003 was estimated as 43,750 km^3 per year which is distributed at the continental level as America has with 24,000 m^3 per year (45%), Asia with 3400 m^3 per year (28%), Europe with 9300 m^3 per year (16%), and Africa with 5000 m^3 per year (9%) [2].

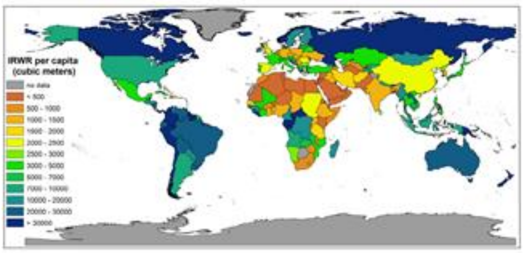

Figure 1: *World map of internal renewable water resources per country in 2012 (data from World Bank Group). [3]*

Water and its scarcity are major and important issues in the world since some decades. That's why, nowadays "scarcity" seems adjective to the word "water". Water scarcity is a rapidly growing problem, especially in limited water availability countries, as it impacts directly to sustainable development [4]–[6]. The misuse of water resources, lack of infrastructure to water supply and climate changes are main reasons of water scarcity. According to the World Economic Forum [7], scarcity will be a main global risk for coming decade because water is being depleted and becoming scarce throughout the globe, which can affect to changing patterns of precipitation in a climate change scenario and effects to demographic development. Nearly, 2.8 billion people are living in water-stressed areas [8] and about half of the world's population will face chronic water by 2030 [9]. Water is one of the most important resources to fulfill the food demand for rapidly increased in population. Extensive water use for irrigation is expected to occur in the context of increasing competition between agriculture and other sectors of the economy. An assessment for water use in agricultural production showed that most of the grabbed countries were located in physical or economic water stress areas [10]. Indonesia, The Philippines and the Democratic Republic of Congo were in the highest grabbed green water rates and Tanzania and Sudan were the most affected by blue water grabbing. The situation was even worse in the Democratic Republic of Congo, where the volume of grabbed green water was almost equal to the amount of green water for food production.

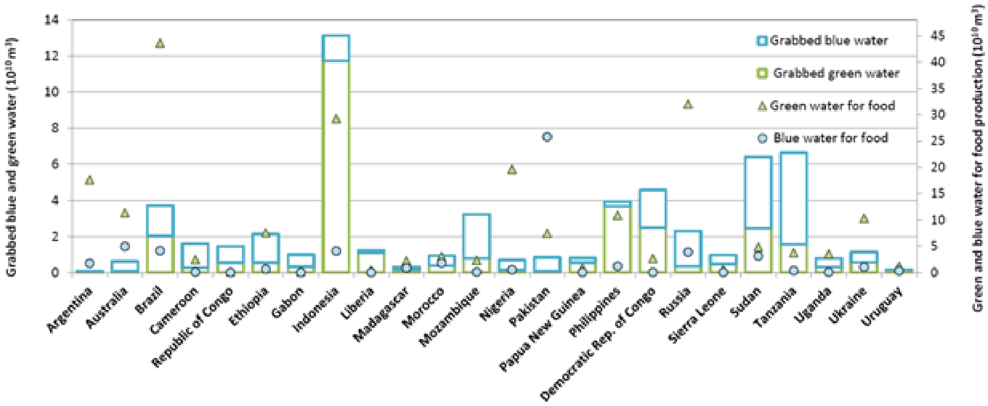

Figure 2: *Volumes of grabbed water and water necessary for food production in the 24 most land-grabbed countries. [10], [11]*

Projected population growth is one of the factors to be considered in water scarcity. The world population is estimated to grow by around 2.3 billion people between 2009 and 2050 and more than two-thirds of the world population could experience water scarcity over the next few decades [12], [13]. Globally, at least 7130 km^3 of water are required to satisfy crop evapotranspiration losses in agriculture [14]. The annual crop water withdrawal as per country is shown in below figure 3.

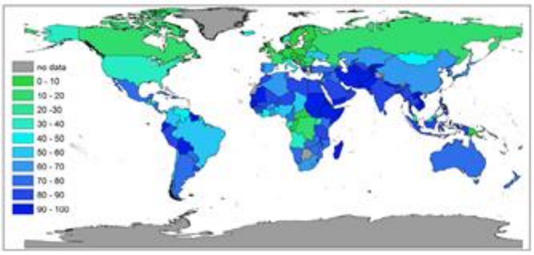

Figure 3: *Annual percentage (%) of fresh water withdrawals in crop production as per country referring to total water withdrawals in 2012 (data from World Bank Group). [3]*

Not only water, but water and energy are the main inputs for agricultural production systems. Efficiently use of surface water and groundwater and energy resources are vital in terms of productivity and economic competitiveness of agriculture as well as for environmental sustainability. Comparing with traditional gravity-based irrigation systems like flood or furrows use more water but the amount of energy used in modern irrigation application like a drip or sprinkler system is significantly high.

The crop production is more in irrigated agriculture than rain-fed agriculture but more than 80% of global agricultural land is rain-fed [14]. However, only 18% global agricultural land is as irrigated land. There are about 20% irrigated land of the global cultivated area which contributes about 40% of crop production [15]. About 24% of global land area and 35% of the global population living in areas are suffering from severe water shortages [16], [17]. Similarly, about 40% of global irrigation practices are unsustainable because of depletion of environmental flows [18], [19]. Fischer et al. (2007), estimated that there will be increased more than 50% irrigation water requirement in future in developing countries and by about 16% in developed countries from 2000 to 2080. The largest relative estimated increases of irrigation water requirements are projected to occur in Africa as (+300%) and Latin America (+119%) in between the 2000 to 2080. Thus, adapting high efficient irrigation method or using low water applications can enhance water sustainability in some water scarce region [21].

2. Literature Review

2.1 Water scarcity and adaption of low water consumed irrigation

More than half of the world population use rice as a main food and it is a crop which secured food security all over the world. But now, there is a challenge to increase the rice production to meet increasing population within limited sources of arable land, irrigation water availability and fertilizer. In Egypt, rice is the main crop of food self-sufficiency that is grow in all season and more than 50% of Egyptians used as a staple food. But most of the part of Egypt are facing water scarcity problem for sustainable development in agricultural production [22], [23]. Due to lack of irrigation water, low water consumed irrigation methods like sprinkler and drip irrigation system are suggested with alternative irrigation water timing and deep groundwater pumped [24], [25]. Similarly, Korea was also self-sufficiency country for a long history for rice cultivation and paddy field irrigation but after Korean War the agriculture has been suffered. Now Korea is one of leading countries adapting advanced irrigation technologies which utilize to overcome challenge in agricultural and water development to support the rapid economic growth to establish nationwide modernized irrigation systems [26]. Indonesia is also suffering with water scarcity. The water demand in irrigation was not balancing in most of the part of the country as Bantul Regency Provine, one of rice barn area before 2006 and balanced in rice supply and demand for 2006 to 2015 [27] and South Sumatera next Province, the Belitang Irrigation System showed water scarcity for crop production because of mismanagement in irrigation system [28]. Similarly, a study in the lower Cimanuk River Basin, West Java, Indonesia showed the coverage water demand was not satisfied to water users to irrigation for food crop production which increase the rate of the scarcity of food need in Indonesia [29]. Punjab and Haryana also known as “bread basket of India”, was popular for good crop production like wheat, rice, maize etc, from where about 60% grain was covered to India i.e. huge grain surplus produced. It was helped to the country for self-sufficiency in food. Faridkot and Muktsar were also two agricultural dominated districts of southwest Punjab but a study indicated that the depletion of groundwater affected to reduce the crop yield and cropped area and switching from more water intensive crop to less water consumed crop made self-sufficiency, saved water usage, labours, fertilizer, and increased in crop production and quality too [30]–[32]. Declining fresh water is a main component of water scarcity in the world [33], [34]. The major factors of water scarcity in fresh water are population growth and urbanization, crop pattern and crop type, energy use and climate change impact [34], [35]. About 70% water available in the world is used in agriculture to sustain global crop production and there is again more probability of water scarcity because of climate change scenarios [36], [37]. In India, about 85% of total water is used in agricultural sector and ground water level is reducing day by day [32]. The study carried in China and Australia showed the irrigation water reduction was 27% and 35% respectively. In Iran, analyzing 10 years of cultivated crops data of South Khorasan Province, showed blue virtual water contributed about 99% of total virtual water. And, overuse of water was due to improper pattern of crop planting [38]. Iran was politically unstable country where future food supply and sufficiency is at stake due to over exploitation of land and water resources but a study with a modeling framework to estimate plant species production influenced for the year 2030, showed that limiting current agricultural water withdrawal is safe level for the environment until 2030 even population increased from 80 to 90 million people led to a decline in self-sufficiency from 83 % to 39% [39]. And a study in Kashan city of Iran which is facing water scarcity in both water quality and quantity, showed that the main reasons of water crisis are lack of land use planning, mismanagement, political decision for water allocation and lack of proper water pricing and rising the water demand and scarcity make decreasing ground water table, water quality and increase the eco system loss [40]. As per Darko et al. (2020) and Lee et al. (2019), several countries of middle, east and north region in Africa were the least food self-sufficiency and high water deficit area in the world, has been now considered irrigation water played as a crucial role to enhance national economy, food security, ensuring access to drinking water for increase population and industrialization of agro-processing. As the efficiency of exiting surface irrigation method is about 40%, so less water consumed and more efficient irrigation method i.e. drip and sprinkler irrigation methods are adapting most of the countries. About 30% farmers in United States, California State switched from surface gravity irrigation system into drip irrigation system [35].

2.2 Impact of irrigation water scarcity

Once the crop water requirement is known, upgrading the irrigation water efficiency is an effective strategy for water savings in agriculture. Global climate change has significant impacts in human life as availability and vulnerability on water resources. As population is increased, crop production is need to increased, thus crop production directly impact to water demand. Nearly 70% of the irrigated area is located in Asian countries and the largest extent of irrigated area is occurred in China, India, United State and Pakistan which altogether occupied about 56% of the global irrigated area [43]. Teesta river catchment area in Bangladesh, in which water flow from India, was badly affected in food production due to irrigation water scarcity. The study in the catchment area showed that about more than 4.45 million metric tons of rice production had been lost in 2006-07 which was about more than the country's total rice import during 2008/09 to 2013/14 fiscal years. The reduced food production reflects the north-western part of the country is insecure in food from its own production [44]. Likewise; a study carried out in California faced effects of water scarcity in intensive water consumed crop such as avocado is expensive while water availability is scarce and reduce the crop yield [45]. Similarly, to expand the cultivation area is a goal of policy of Brazil but it is restricted to 54% for an acceptable water scarcity level because of water scarcity in irrigation. This made effects on sustainability in crop production [45], [46]. The water scarcity, especially on surface water dominated irrigation is more vulnerable drought impact on low flow than high flow conditions [43] and in Poland, the effective measure to prevent the harmful effects of droughts and water scarcity in crop production are optimized application of irrigation water, crop rotation and modernization of irrigation method [47].

2.3 Expression of irrigation water scarcity and sufficiency

Equation for water sufficiency

Irrigation water sufficiency is defined as the ratio of water availability to water demand in the study area. The agricultural region general considers as water sufficient if the total water available in the basin (catchment) can fulfill its total demand. Virk et al. (2020) expressed water sufficiency in the form of water sufficiency ratio (WSR) defined as:

$$\mathrm{WSR} = \mathrm{W_a}/(\mathrm{W_c})$$

Where,
Wa is available ground water
Wc is the consumed groundwater
Based on the value of WSR, water sufficiency is defined as,
Insufficient: WSR < 1,
Sufficient: WSR > 1,
Balanced: WSR = 1

According to Rygaard et al. (2011) expressed water self-sufficiency as Qlr/Qtd.
Where,
Qlr is the amount of water sourced from within a given area, and limited to recycled wastewater, harvested rainwater or desalinated water from local shores.

Qtd is the total water demand in the same area, e.g. a single building or a larger urban area. The definition employed shows that the self-sufficiency ratio depends on the definition of the area or system boundaries and so it is important to use consistent boundary definitions in every case.

Similarly, level of local self-sufficiency at time t is used as:

$$\mathrm{NPK_t} = \mathrm{NP_t}/\mathrm{NK_t}$$

Where,
NPK_t is level of local self-sufficiency at time t,
NP_t is net production at time t,
NK_t is consumption at time t, and t is time.

Increase and decrease of paddy field area and population growth

For decreasing of paddy field area is calculated based on the following Equation,

$$r = \frac{L_t - L_{t-1}}{L_{t-1}} * 100\%$$

Where,

L_t is land area for year t,

L_{t-1} is land area for previous year's,

r is rate of declining land area

The population growth is calculated as,

$P_t = P_o(1 + r.t)$

Where,

P_t is number of population at t,

P_o is initial population,

r is population growth rate,

t is time in year.

Similarly, the prediction of rice consumption is given by,

$$D = \frac{PxR_{ci}}{1000}$$

Where,

D is rice consumption per year (ton),

P is number of population,

Rci is Rice consumption Index (kg/capita/year) and 1000 is conversion number.

And, the rice production is estimated as,

$$L_p = IP * L$$

Where,

Lp is harvested area for one year (ha),

IP is cropping index,

L is planted area (ha).

Similarly,

$$S_1 = \frac{L_p * P_r}{10}$$

Where,

S_1 is milled dry grain production a year (tons),

Pr is productivity in quintal per ha (kw per ha) and 10 is conversion number.

And,

$$S_2 = S_1 * akg$$

Where,

S_2 is rice production a year (tons),

akg is conversion number from milled dry grain to rice.

Equation for water scarcity

Water scarcity is lack of access to adequate quantities of water for human and environmental uses. One of the most commonly used measures of water scarcity is the 'Falkenmark indicator' or 'water stress index'. This method defines water scarcity in terms of the total water resources that are available to the population of a region; measuring scarcity as the amount of renewable freshwater that is available for each person each year. If the amount of renewable water in a country is below 1,700 m^3 per person per year, that country is said to be experiencing water stress; below 1,000 m3 it is said to be experiencing water scarcity; and below 500 m^3 , absolute water scarcity [50]. The water stress index method is commonly used because of straightforward, easy to use, and the data needed is readily available. Many earlier studies assessed water scarcity using an index called the Withdrawal to Water Resources (WWR) ratio. The index expresses annual water withdrawal as a function of annual renewable water resources. WWR = W/Q, where Q is the annual renewable water resource, typically substituted with mean annual river discharge and W is the annual total water withdrawal. If water withdrawal exceeds 40 % of the water resources in a region, a chronic water shortage is indicated. This index is widely used, probably because it is intuitive and requires only two factors (W and Q) that are relatively easily available [51].

2.3 Irrigation water scarcity and sufficiency in Jhikhukhola watershed

Rice is the major food crop all over the Nepal [52], [53]. So, it is important crop as a production and economic growth of the developing countries like Nepal. Due to rapidly increase in population growth and urbanization, changing river course, excessive abstraction of groundwater, high water demanding crop and inefficient irrigation for rice based farming make problem in self-sufficiency in rice production and future food security. The climate change also intensively increases the water problem in agriculture and future food grains. Thus, even there are irrigation water decline continuously every year [54], development of efficient irrigation system and adaptive measures under proper policy can support for self-sufficiency in food [52]. Nepal is trying to self-sufficiency in rice production by adopting direct seeded rice cultivation technology which helps to adapt in water scarcity and climate change scenario. It reduces irrigation water demand and labor use by 50% and production is increase by 5 to 10% more than yield of transplanted rice [53]. The Jhikhukhola watershed, a 45 km far at east from Kathmandu, the capital city of Nepal lies in Kavrepalanchowk District. The catchment area of the watershed is about 11,141 ha. There is only one river i.e. Jhikhukhola, say the lifeblood of Jhikhukhola watershed [55], in general dry period from November to January and a very wet monsoon from June to September. The elevation ranges from 750 to 2,050 masl and is characterized by high vertical relief, steep slopes, and shallow soils.

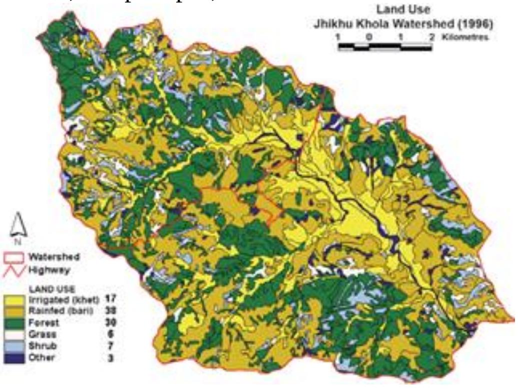

Figure 4: Land use of the Jhikhukhola based on LRMP 1986 [56]

Water is one of Nepal's major concerns because of too much water during the monsoon and too little water during the dry winter months. The Jhikhukhola watershed is economically very active in terms of agriculture as its market is near to Dhulikhel, Banepa and Kathmandu as most of the land in the watershed is covered by crop production. It was showed in Icimod, (2007) report as 55% of total land was covered for agricultural land and for forest, grassland, and shrubland was 42%; and remaining for other uses was 3%. But a survey in Jhikhukhola watershed as per Merz et al. (2003) showed that 33% shortage of water for irrigation; 27% shortage of drinking water; and 17% in the identified drinking water quality was the major problem and this shortages are still in continued in Jhikhukhola watershed.

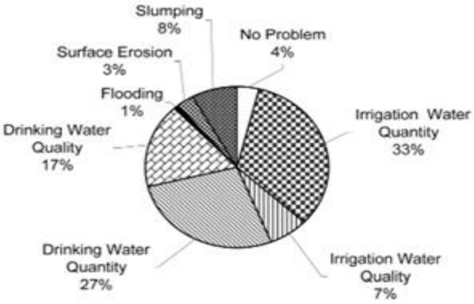

Figure 5: Water issue in Jhikhukhola watershed

2.4 Water demand and availability for agriculture

About 77% people of the Jhikhukhola watershed were involved in agriculture as their main occupation. The Jhikhukhola watershed was highly population increased land which builds pressure through intensification of land use. Farmers in the watershed had been grown three to four commercial crops at appropriate site per year with high inputs of labour, irrigation, chemical fertilizers and pesticides. Cropping intensity on irrigated agricultural land was increased from 213% in 1994 to 226% in 2004. The required increased water demand is generally due to vegetable farming during the pre-monsoon and to a lesser extent the post-monsoon seasons.Water availability in the Jhikhukhola watershed was carried out by analysing monthly, seasonal, and annual rainfall data measurements. The average annual precipitation was 1,338 mm; with upper and lower limits of probable annual rainfall of 1,538 mm and 1,138 mm, respectively. The upper limit for rainfall was 232 mm (15%) in pre-monsoon; 1,141 mm (78%) in the monsoon; 102 mm (5%) post-monsoon; and 63 mm (3%) in winter.

2.5 Irrigation water management

To minimize the water scarcity in the Jhikhukhola watershed, a study on a combined attempt of a technology in small household level with community based participatory approach was suitable to manage the water resources. The studied options of the technology were method of improvement in water infiltration into the soil, method of water harvesting and improvement of water use efficiency approaches. By reducing the slope of terrain from 50% to 5%, which reduce direct runoff and increase infiltration, helped to improve the soil moisture status and productivity. Eyebrow-pitting was another option for rainwater harvesting which also improve infiltration and soil moisture. And, by protecting water source with structure measures and supporting by plant grass and tree in the catchment area helped to conserve water availability.

Figure 6: Improvement of water infiltration with constructing water collection pit

Water harvesting

Even soil is good for crop production in Jhikhukhola watershed area, the upland farmers were restricted to a single crop because of constraint of water availability and below valley bottom with irrigation facilities farmers grew multiple crop. One of the possibilities to collect water for irrigation is to store excess runoff water in conservation ponds or recharge to groundwater and use when the crop water requirement is higher than rainfall. A study on an option of collecting excess water in plastic-lined conservation ponds and in underground cisterns for later use in irrigation helped to harvest water availability. Such conservation ponds integration with drip and sprinkler irrigation systems, and vegetable and fish farming helped to enhance the farmer economic benefit.

Figure 7: Plastic covered pond Figure 8: Roof water collection (harvesting)

Wells located on the slope were fast recharged and water table also dropped very quickly after rainfall ceased as compared to wells located near to stream, in which differences of water table was very low as the wells benefits to discharge through river flow. In general, wells located near to stream were more reliable to get more water yield.

A concept of irrigation canal, runoff harvest ponds, dug wells, conservation pond with efficient water use technologies like drip and sprinkle irrigation methods helped to reduce crop water requirement for vegetable farming in Jhukhukhola watershed. Farmers in the Jhikhukhola watershed have been growing high valued cash crops because of easy access to big markets Dhulikhel, Banepa and Kathmandu even in pre-monsoon season, a great scarcity of water period (March to May) vegetables like bitter gourd, cucumber, cauliflower and tomato. Drip irrigation, which is a slow and precise delivery of water around the root zone which saved about 60% of water in all soil types and 50% labour compared to bucket irrigation without reducing yield, also helped to mature the crop earlier; and the harvest was about three weeks earlier than usual in the Jhukhukhola watershed [56].

Another successful experiences in Jhikhukhola watershed to reduce crop water requirement was the system of rice intensification in which 8-12 day-old 2-leaf seedlings were planted at a wide spacing i.e. 25 cm x 25 cm or even wider. Then, a small amount of water was applied to prepare the field for transplanting. When the land started to cracking; only then light irrigation was given to moisten the soil. Alternate dry and moist soil conditions improved aeration and also helps to plants grew vigorously and the study found that the system of rice intensification reduced 50 to75% less water than the traditional method and also reduced frequency of irrigation.

3. Conclusion

Most of the world water is used in agricultural production even though there is an increase in water demand in irrigation to meet the crop sufficiency because of increase of population and rapid urbanization. So, almost parts of the world have a challenge in water sufficiency in irrigation. Deficit irrigation reduces the crop production at water scarcity time, so to manage deficit irrigation water is important to secure water to be used in crop production and food security [58]. The optimal irrigation scheduling and less water consumed irrigation method provides more effective water content during the entire growing season within the root zone [37] which help to manage the scared water availability.

Drying sources of water resources indicates that water scarcity is not only due to scarcity of water but also scarcity of management. One of the ways to reduce the additional crop water requirement is modifying the cropping pattern with integrating efficient irrigation technique in various ways. As Jhikhukhola watershed is one of the best land for agriculture but it is required to study a comprehensive study on different types of water demand and water sufficiency in irrigation. The study will helps us to understand water availability status, develop strategies and improving the deficit between water supply and demand for future economic, environmental and social developments.

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