Review Article

Revitalizing Key Conditions and Integrated Watershed Management Approach to Sustain Water Availability and Agriculture in Semi-Arid Regions

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Integrated watershed management is regarded as the best approach to prevent and rehabilitate watersheds and improve livelihoods. So far, some achievements have been made in terms of soil and water conservation activities. Yet, based on literature reviews and personal observations, there are various constraints that impede the successful implementation of the approach. These include poor institutional and policy support, lack of participation, poor planning of soil and water conservation, inappropriate use of technologies, failure to utilize scientific inputs, and lack of capacity building. To revitalize the successful implementation of the approach, key conditions for consideration include assuring institutional, legal, and policy support, practicing proper soil and water resource management, securing access to integrated agricultural inputs, and establishing scientific and technology support in a watershed. Hence, amending the approach and integrating all these key conditions in the approach are quite crucial for the sustainability of water availability and agriculture in semi-arid regions in particular.

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1. Introduction

Global desertification is recognized as a major environmental problem caused by a combination of social, economic, and biophysical factors, operating at varying scales that impair various ecosystem services and degrade natural resources such as land, water, vegetation, and biodiversity (Elaine et al., 2013).

Land degradation and continuous desertification, caused by climate variability and global warming, human activities, and poor land management practices, are fueled by high population pressure, soil erosion by wind and water, low and highly variable rainfall, low rainwater use efficiency, poverty, low investments in water use efficiency measures, and inappropriate policies. These factors may drive these regions to total collapse in a short time in the absence of timely and appropriate measures (Pathak et al., 2009; Elaine et al., 2013; IISD, 2003; Magaly and Thomas, 2016; Koohafkan and Stewart, 2008). So far, desertification has already affected significant parts (70%) of the world, making lands devoid of vegetation cover with severe soil erosion, sediment detachment, and transportation during torrential floods, siltation of dams, etc. Dryland regions already occupy almost 40% of the world's land area and are known for their recurrent droughts, water scarcity, limited water supply, fragile ecosystems, and vulnerable environment (IISD, 2003).

However, the global drylands are inhabited by a significant percentage (nearly 40%) of the global population, mainly those who are poorest (Koohafkan and Stewart, 2008). More than 20% of the world's rapidly growing population currently lives in areas with physical scarcity of water, though access to water resources remains critical for people's health and well-being (Magaly and Thomas, 2016). In Africa, 41% of the population resides in drylands, with even more (50%) in Sub-Saharan Africa (SSA), where there is the highest (70%) aridity coverage (Suhas et al., 2011) and most (75%) of its people are poor and engaged in agriculture (Christopher et al., 2016). Agriculture in SSA is predominantly (60%) rainfed, generating 30-40% of GDP in each country of the region (Binyam and Desale, 2015). Moreover, this sector withdraws 87% of total water across SSA, which is more than the worldwide agricultural share (about 70%). Among the dryland countries in SSA, the Eastern African countries (Ethiopia, Kenya, and Sudan) withdraw the largest volume of water (44% of total withdrawals) for agriculture (Christopher et al., 2016).

Of the total global drylands, 12% is arid, 18% is semi-arid, and 10% is dry sub-humid (Koohafkan and Stewart, 2008), indicating that semi-arid regions have dominant coverage with a significant position in the globe. They are home to 38% of the world's poor, 45% of the world's hungry, and 70% of the world's malnourished. To improve food security and reduce poverty in the global drylands, there must be success in semi-arid regions in particular, considering the fact that further global climate change may also convert parts of the semi-arid tropics to complete arid regions with possibilities of more frequent fluctuations of rainfall and increased frequency of extreme events (Suhas et al., 2011).

Water requirements of most dryland crops are not usually fulfilled by water availability from rainfall, and water from any source is also scarce in drylands. Consequently, crop yields are either minimal or nil due to both critical water scarcity and low soil fertility of drylands. Farming in this region, thus, demands water and soil conservation and management. Improved management of land and water resources in watersheds can counter desertification (due to overgrazing and deforestation), increase the productivity of low-rainfall areas (Koohafkan and Stewart, 2008), and improve ecosystem and livelihood resilience to climate changes (Suhas et al., 2011).

The implementation of integrated watershed management (IWSM) has been perceived as the best approach to prevent and rehabilitate watersheds and ensure the preservation, conservation, and sustainability of all land resources for improving the living conditions of the people throughout a watershed. So far, various soil and water conservation interventions have been implemented in developing countries such as in SSA. Some successes have been achieved in converting different degraded sites to productive areas, though the sustainability of water availability and agriculture is insignificant. Also, failures of different watershed management measures were observed as a result of various constraints of watershed management (Tesfu and Sangharsh, 2015; Gadisa, 2016; Daniel, 2020).

Considering the significant coverage of semiarid regions over the globe, the risk of total conversion of semiarid to arid regions, the ease of reclamation of semiarid regions, intervening on semiarid regions with due focus to key conditions, and amendment of the IWSM approach are highly recommended to sustain water availability for agriculture and other uses in those regions. Hence, identifying constraints of the IWSM approach and specific key conditions in promoting IWSM can contribute to reclaiming and retarding the process of changes from semiarid to arid regions while improving water availability for agriculture and other uses to ultimately improve the livelihood in a specific watershed.

It is thus important to timely revitalize key conditions as well as amend IWSM, and this literature review attempts to sort out IWSM constraints and key conditions that need to be considered in rehabilitating and managing watersheds for sustainable water availability for agricultural development and livelihood changes in semiarid regions in particular.

2. Characteristics and challenges of water availability and agriculture in drylands

2.1. Characteristics

Drylands are generally characterized by a combination of low precipitation, high temperatures, and drying winds. According to UNESCO (United Nations Educational, Scientific and Cultural Organization), drylands are classified based on the aridity index (AI) as: hyper-arid (AI < 0.05); arid (0.05 < AI < 0.20); semi-arid (0.20 < AI < 0.50); and dry sub-humid (0.50 < AI < 0.65) (Christopher et al., 2016; Koohafkan and Stewart, 2008). They can also be categorized on the basis of the length of the growing period (LGP) for annual crops, rainfall, and aridity as arid regions having up to 59 growing days, semi-arid regions having 60–119 growing days, and dry sub-humid regions having 120–179 growing days (Koohafkan and Stewart, 2008).

These regions are characterized by a commonly dropping trend of water sources (water table, spring, and river flow), leading to water scarcity and competition for water between agriculture and other multiple uses in the face of more frequent extreme weather predictions and greater aridity resulting from climate change. The droughts in drylands can be classified as: meteorological drought ("a measure of the departure of precipitation from normal"), agricultural drought ("situations where the amount of soil water is no longer sufficient to meet the needs of a particular crop"), hydrological drought ("occurs when surface and subsurface water supplies are below normal"), and socioeconomic drought ("describes the situation that occurs when physical water shortages begin to affect people") (Koohafkan and Stewart, 2008). In addition to these, industrial pollution from urban settlements pollutes water resources and contributes to water degradation (Suhas et al., 2011).

The intensity of rainfall in such regions (e.g., in SSA) is usually greater than the soil infiltration rate and soil water holding capacity, which triggers runoff generation from the surface. The rainfall in this region is characterized by high losses of water due to excessive surface runoff following intensive rains, high evaporation during pre-planting and early crop growth stages (Binyam and Desale, 2015). In line with this, only 19.7% of the rainfall in SSA becomes available water for crops, which implies that the poor crop yields and crop failures in these regions are not due mainly to low rainfall but due to wastage of valuable rainwater (Suhas et al., 2011). Moreover, uncontrolled runoff turns into aggressive and damaging flash floods, causing severe erosion, increased turbidity, and substantial water losses. Following these losses of valuable water resources, the chances for increased food insecurity, poverty, and subsequent threats to sustainable development in SSA are imminent. The erratic nature of the rainfall in this region, aggravated by climate change, is expected to increase its variability (Binyam and Desale, 2015).

Dryland farming is practiced in regions where a lack of soil moisture limits crop or pasture production to part of the year, and water management plays a decisive role. It is thus dependent solely on the water available from precipitation and on having stored soil water at the time of seeding to supplement the rainfall during the growing season (Koohafkan and Stewart, 2008). However, the hydrology of semiarid regions reveals that about 90% of water is often lost in the form of runoff during stormy rain, with only 10% left for productive transpiration and in the form of evaporation during times of low intensity. As shown in Fig.1, about 15 to 30% of the precipitation is used for transpiration, while a similar amount is lost as runoff, and 30 to 50% is lost as evaporation (Koohafkan and Stewart, 2008; Suhas et al., 2011).

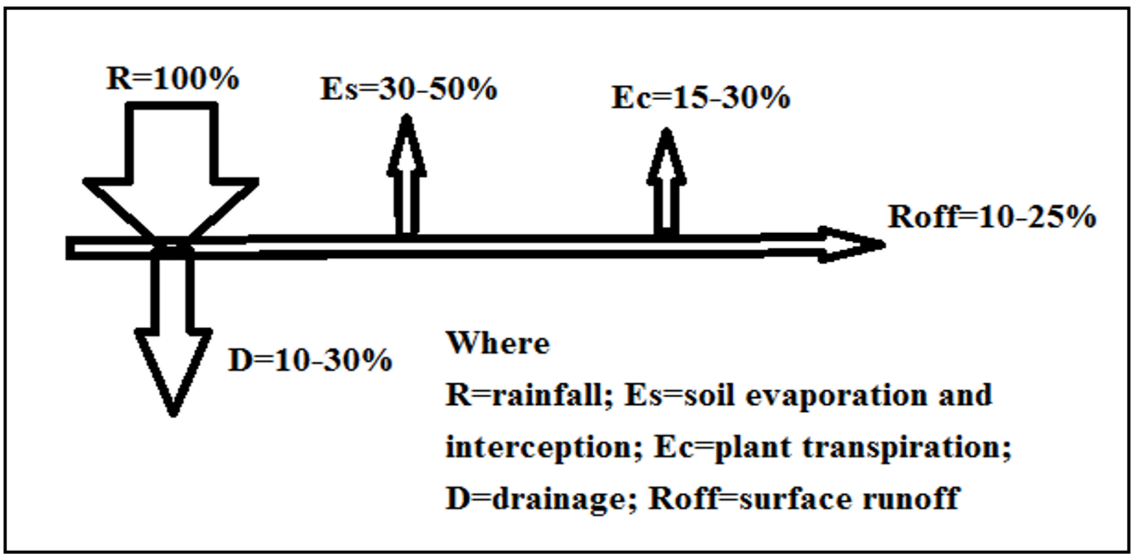

Figure 1. Rainfall partitioning in semiarid regions (Koohafkan and Stewart, 2008)

The water balance in semi-arid regions (Fig.1) clearly indicates that a large proportion of rainfall (as much as 70% of non-productive components of precipitation) may not be used directly in dryland crop production. The cause for this shortcoming could be due to soil fertility depletion or soil physical deterioration (which in turn reduces infiltration and water holding capacity) through the oxidation of organic matter (Koohafkan and Stewart, 2008). Desertification can thus be seen as a direct cause for soil

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nutrient losses, decreased infiltration and soil water holding capacity, and impaired primary productivity (Elaine et al., 2013).

Considering the fact that most of the rainfall is lost by runoff and surface evaporation, groundwater recharge in the form of seepage through the soil profile is limited in drylands. Groundwater recharge is largely dependent on the amount, intensity, and duration of the rainfall and soil properties (including infiltration capacity and water holding characteristics of the soil) (Koohafkan and Stewart, 2008). The water balance in semiarid regions (Fig.1) implies that there is great scope and opportunity to exploit benefits from such water balances through suitable watershed interventions and improvements of water productivity by shifting the non-productive components (evaporation and runoff) to the productive component (transpiration) (Suhas et al., 2011).

2.2. Challenges in Drylands

The rapid population growth in drylands has placed tremendous pressure on the natural resource base (Koohafkan and Stewart, 2008). This pressure is exacerbated by deforestation, land use change, and unwise management of water resources, which result in the alteration of watershed water flows and hydrological processes (Gebremedhin et al., 2019). Additionally, croplands are often badly eroded due to the unfavorable trends of rapid population growth, which cause landlessness, add more pressure on grazing and forests, and lead to encroachment onto marginal land (Suhas et al., 2011). The population increase in drylands, mostly in many developing countries, also leads to increasing water requirements for various uses, such as industry and domestic use, at the expense of irrigation needs. This increase is complicated by different forms of water wastage, mainly due to the difficulty of managing water (Koohafkan and Stewart, 2008).

Increased migration of people in drylands may also lead to conflicts over access to natural resources, primarily water resources for livestock drinking and crop irrigation. Inappropriate livestock grazing practices are usually considered the culprit causing rangeland degradation and desertification (Elaine et al., 2013). Land degradation in resource-poor areas due to increasing population contributes to the loss of the land's production capacity. People are forced to live in increasing insecurity due to land degradation and desertification (Koohafkan and Stewart, 2008), as there are usually losses of soil surface layers rich in nutrients and organic matter. These losses reduce fertility at a maximum global erosion rate of 30-40 t ha-1yr-1, while the sustainable rate (soil formation rate) is 1 t ha-1yr-1 (Suhas et al., 2011). The productive land per capita also diminishes subsequently. Dryland farming has generally been inefficient due to the poverty trap, as the poor cannot afford to invest sufficiently in capital-intensive resources (Koohafkan and Stewart, 2008).

In the course of preventing land degradation in semiarid regions, insufficient precipitation seriously limits organic matter production, and warm conditions generally accelerate the decomposition of in-situ soil organic matter during periods of favorable soil-water conditions. On top of these, crop residues are often removed for livestock feed or household fuel in many developing countries, and there are also tendencies toward the production of biofuels in the future (Koohafkan and Stewart, 2008).

Current dryland farming can thus be considered a risky enterprise, affected by drought (a principal hazard). Insects, hail, intense torrential rains, and high winds can also damage or destroy crops. As there is no strong preparedness and little can be done to prevent most sudden disasters, working on soil- and crop-management practices can reduce the impact, particularly on droughts, since low soil-water content in dryland areas commonly restricts crop yields. Additionally, several other soil problems (surface-soil hardening, compaction, water and wind erosion, low soil fertility, shallow soils, restricted soil drainage, and salinization) can also affect dryland farming (ibid).

In semiarid regions of Asia and Africa, it has been revealed that there are large yield gaps, with farmers' yields being two to four times lower than achievable yields for major rainfed crops (Suhas et al., 2011). Crop water productivity in the SSA drylands is thus generally low due to combined factors of poor water management, poor soil management, and poor crop management (Christopher et al., 2016).

Moreover, drylands all over the world face difficulty in maintaining water resources to meet intensified demands in the future as population increases, infrastructure development expands, agricultural water demands increase, and climate change impacts the hydrologic system (Magaly and Thomas, 2016). In the absence of groundwater recharge and replenishable groundwater resources, there might be practices of extraction of fossil groundwater, often referred to as mining, as it is a nonrenewable resource. Under continued fossil groundwater mining and depletion of other natural resources without taking measures in time, farming practice may reach an irreversible end (Koohafkan and Stewart, 2008).

3. Revitalizing the Integrated Watershed Management Approach

3.1. IWSM Approach and Its Focus

Integrated Watershed Management (IWSM) is essentially defined as "an adaptive, integrated, and multidisciplinary systems approach to management that aims to preserve productivity and ecosystem integrity regarding the water, soil, plants, and animals within a watershed, thereby protecting and restoring ecosystem services for environmental, social, and economic benefit" (Guangyu et al., 2016; Gadisa, 2016). It can thus integrate key conditions for sustaining water availability and agriculture and improving livelihoods as it can create a good opportunity to manage land and water resources in a watershed in an integrated manner to realize sustainable livelihoods while protecting the environment. More specifically, it seems to be the most rational and appropriate approach to simultaneously implement water and soil activities in an integrated manner (Suhas et al., 2011).

In the IWSM approach, a watershed is considered a planning and development entity where water, ecosystem, and human needs are taken into account simultaneously. This approach identifies and builds upon mutually supportive approaches across sectors in which synergies can be explored (Elaine et al., 2013). The sustainable management of drylands is essential for achieving food security and conserving biomass and biodiversity of global significance. For planning and managing natural and agricultural resources in drylands, the characteristics of those resources need to be specified first. These characteristics include multiple crop-livestock-tree and market-related innovations for diversified livelihoods and resilience against changes due to globalization and climate change (Koohafkan and Stewart, 2008).

To properly manage land and water resources in drylands, key conditions for water availability and multiple uses need to be revitalized. The IWSM approach can be implemented to rehabilitate and manage degraded areas by improving the nature of the watershed, minimizing material detachment, reducing the quantity of flooding and sediment load of floods, improving recharge, and creating favorable conditions for the expansion of irrigation (ibid). This approach also supports other socio-economic activities (such as apiculture, animal fattening, aquaculture, agribusiness, etc.) within a specific watershed in an integrated manner.

In the IWSM approach, watershed processes need to be viewed as cause-effect relationships. Erosion and material detachment usually occur at the upper part of a watershed due to deforestation and improper land husbandry. Flooding, erosion, and deposition occur at the downstream part of a watershed as a consequence of upstream degradation. Every intervention upstream of a watershed can be seen as a cause for downstream negative effects in terms of flooding, reduction of water flows, and sedimentation. However, these interventions can also have positive effects, such as recharge or increase of water sources, reduction of flooding, and sedimentation. Considering this reality, site-specific (watershed-based) solutions with synergies between multiple water uses and anti-desertification efforts can be promoted.

Through the synchrony of rangeland conservation and better farming practices, degraded lands could be brought back to productive land use while restoring surface vegetation and soil functions, particularly the water retention capacity of soils (Elaine et al., 2013).

To meet future food demands and improve the rural livelihoods of the growing population, it is recommended to upgrade (invest more in) rainfed agriculture to enhance agricultural productivity, manage both rainfed and irrigated agriculture to enhance resource efficiency and agricultural productivity without creating a distinction between the two, and invest in irrigation to expand irrigation and improve the efficiency of existing irrigation systems within a watershed. IWSM remains an effective approach to handle all these issues by integrating technical, institutional, and social dimensions with knowledge-intensive directions and strong capacity building for all stakeholders, including policy makers, researchers, development agents, and farmers. It can thus integrate sustainable management of natural resources through collective action for improving livelihoods in harmony with nature (Suhas et al., 2011).

The disintegrated approach, which is regarded as "business as usual," cannot significantly contribute to reducing poverty, sustaining economic growth, and ensuring food security in semiarid regions. There is, thus, an urgent need to develop a new paradigm shift in upgrading rainfed agriculture within a specific watershed through the IWSM approach (ibid).

3.2. Constraints of the IWSM Approach

From the experiences of IWSM interventions, the approach has been restricted to mere implementation of soil and water conservation activities that may contribute to the availability of surface and subsurface water by arresting runoff and reducing erosion hazard, while the expectations are moving towards the integration of social, economic, and environmental development (Guangyu et al., 2016).

Among others, the problems that impede meeting the objectives of IWSM include: *i) poor institutional and policy support* (lack of awareness among policymakers on trends and impacts of degradation, poor policy definition and implementation constraints, lack of commitments to address the problems, poor linkage between concerned institutions, poor sharing of information between different departments, lack of equitable and fair sharing benefits between and among upstream-downstream communities, lack of sustainable funding, continued follow-up and maintenance as they are mostly funded by projects with limited periods of time and institutional arrangements, lack of upstream-downstream synergy to resolve conflicts of interest and assure mutual benefits by avoiding a "cash dependent mentality" in the absence of enough resources in developing countries), *ii) lack of participation* (inadequate community participation, disregarding indigenous knowledge, ignoring the interests of rural communities), *iii) poor plan of soil and water conservation (SWC) measures/technologies* (lack of site-specific conservation plans, lack of land suitability studies and scientific design, inappropriate application of SWC techniques, lack of use of a combination of technologies specific to a watershed), *iv) inappropriate technologies and failure to utilize scientific inputs* (lack of scientific approach and technical knowledge, inappropriate technological preferences, inability to transfer technologies and scientific research results into site-specific problems, limited efforts to link watershed management activities with scientific research), *v) lack of capacity building* (shortage of skillful manpower) (Tesfu and Sangharsh, 2015; Gadisa, 2016; Guangyu et al., 2016; Daniel, 2020).

Considering all the aforementioned constraints of IWSM in semiarid regions in particular, various key conditions are discussed to revitalize water availability and agriculture in semiarid regions by taking watersheds as an entry point to realize sustainable livelihood improvements (Suhas et al., 2011).

4. Key conditions that need focus in the IWSM approach

For successful implementation of the IWSM approach, it would be crucial to focus on the following key conditions that need to be checked and incorporated in every watershed for sustaining water availability and agriculture in semiarid regions in particular.

4.1. First key condition: Assuring institutional, legal, and policy support

4.1.1. Institutional support

Every watershed needs to have a specific organization responsible for sustainable development and management. The organization responsible for a watershed needs to be specified with clear duties, and be efficient and effective for the successful implementation of IWSM. The watershed-based organization needs to involve all actors with a stake within the watershed, including upstream and downstream communities, local administrators, experts from various sectors, researchers from universities and research centers, NGOs, etc. The participation of the community in IWSM should not be viewed merely as a benefit (such as earning a salary) during watershed activities. Rather, their participation is crucial for the success of IWSM (Pankaj et al., 2019), and it should be seen as creating a favorable condition for sustainable water availability and subsequent socio-economic activity (such as irrigation, apiculture, animal feed development and fattening, aquaculture, agribusiness, etc.) throughout a watershed. The institutional arrangement for a watershed also needs to create capacity-building opportunities.

4.1.2. Assuring legal and policy support

Poverty, drought, and conflicts over resources in drylands usually occur simultaneously where there is degradation. These problems could be avoided by intensifying agricultural production and safeguarding pastoral mobility. Furthermore, rangelands in a specific watershed could even be utilized as platforms to increase water productivity by judiciously using them as a feed source while avoiding overgrazing. This requires setting appropriate policies to handle transboundary herd movements while creating corridors, water points, and resting areas to avoid the concentration of too many animals around one watering point, which may otherwise cause soil and vegetation degradation and water contamination.

Moreover, drought-resistant plants, arboreal pastures, and perennial grasses can be cultivated in a landscape, and rangelands can be improved by transforming them into arboreal pastures. Providing incentives to livestock herders to improve herd management and safeguard the regulation and support of ecosystem services are more sustainable exploitation options for agropastoralists. In dealing with agropastoralism and dryland problems, positive changes have been noticed following increased exchanges and closer collaboration through increased interaction between pastoralists and farmers. Hence, policy support to facilitate the adoption and dissemination of good practices is required. A total shift towards more integrated approaches of agro-ecosystem management that integrates crops, trees, livestock, and, in some cases, aquaculture to enhance resource recovery and the reuse of resources for feed or soil fertility is also required (Elaine et al., 2013).

Towards assuring legal and policy support, there are exemplary countries in the world that have coped with a dryland environment. Israel is one of those countries considered the most water-scarce in the world. It has acquired good experiences in dryland water management to cope with the challenges of water management through various key water sector innovations. In this country, most (about 70%) of its rainfall is lost to evaporation, and approximately 25% infiltrates to groundwater or remains in the soil to support vegetation and crops; only 5% flows as surface water. The water scarcity in this country has shaped the development of its water sector as it has had no choice but to adapt and gradually develop a series of water innovations in operational practices, technologies, and institutions. Indeed, the country has gradually implemented a policy that combines institutional reforms and massive infrastructural investment to achieve a reliable water supply. This policy included six elements: strong demand management (water permits and metering), reuse of treated wastewater for irrigation, developing large-scale desalination of seawater, developing a national bulk water conveyance infrastructure for conveying surpluses of water from one place to another, recharging and using aquifers as reservoirs, and making institutional reforms to promote the financial sustainability of the water sector as a whole, and separate political decisions from infrastructure planning and operations (Philippe et al., 2017).

4.2. Second key condition: Assuring proper soil and water resource management in a watershed

4.2.1. Implementation of appropriate soil and water conservation (SWC) measures suitable to a specific watershed

In order to upgrade and achieve the potential of rainfed agriculture available within each watershed, the implementation of soil and water conservation (SWC) measures is believed to be an entry point (Suhas et al., 2011). Indeed, the successful implementation of SWC measures in a watershed is considered one of the decisive conditions to improve soil organic matter and soil water holding capacity and ultimately water recharge and availability on a sustainable basis in a specific watershed of semiarid regions. To this effect, appropriate SWC measures need to be selected and implemented based on a suitability map that integrates biophysical and socioeconomic characteristics. These include watershed hydrogeology, hydrology, land use, slope, community preference, livelihood, etc.

It is promising that SWC measures can play a critical role in increasing and sustaining agricultural productivity in rainfed areas in fragile agro-ecosystems (ibid). SWC measures can contribute to increased watershed-level recharge of rainwater in the soil by retarding/minimizing the movement of surface runoff and prolonging the opportunity time for infiltration and/or directly concentrating it where the water is most wanted or needed to be stored (Binyam and Desale, 2015; Suhas et al., 2011). The implementation of SWC measures can be regarded as a win-win solution to create opportunities for increased water availability for different uses while reducing the negative consequences caused by surface runoff (Suhas et al., 2011). Retaining freshwater sources through SWC, such as in existing oases, is also quite critical to support rural human populations with a high diversity of vegetative types in dry regions (Magaly and Thomas, 2016).

Effective management of soil erosion, rainfall, runoff, and groundwater in rainfed agriculture can thus be realized through the implementation of various SWC measures (that include water harvesting structures and groundwater recharging measures) and supplemental irrigation at this scale (Suhas et al., 2011). Hence, SWC can be regarded as the first step to rehabilitate degraded land and improve soil moisture in drylands by retaining moisture, reducing runoff, reducing evaporation, and improving infiltration and altering the typical hydrological characteristics of semi-arid regions as shown in Fig 1. SWC can also contribute to the easy reestablishment of vegetation cover and reduction of soil erosion from degraded areas to improve crop growth and address poverty through increased productivity (by increasing yields and reducing the risk of crop failure), diversified agriculture (horticultural cash crops, rearing dairy animals) (Binyam and Desale, 2015).

4.2.2. Reconditioning soil resources for water management

Dryland soils usually have low organic content and soil fertility due to little deposition, accumulation, or decomposition of organic material as land degradation decreases infiltration, soil water holding capacity, and transpiration while enhancing runoff and soil evaporation. Moreover, the soils in these regions often cannot absorb all of the rain, especially during large storms. Hence, in examining and reconditioning the soils, the important features for consideration include: water holding capacity and the ability to supply nutrients to plants (Koohafkan and Stewart, 2008; Suhas et al., 2011).

The soils in these regions typically have negative nutrient balances of major plant nutrients (N, P, and K), secondary nutrients (such as S), and micronutrients (such as B and Zn), as well as soil organic matter. Depletion of these nutrients remains a major constraint to sustaining rainfed agricultural systems in semiarid regions (such as in Asia and SSA). Balanced plant nutrition contributes to increased crop productivity and crop quality in grain and stover/straw, with implications for nutrition in grain as food for humans and straw as feed for animals. However, critical soil moisture stress due to erratic and low rainfall is the major bottleneck for farmers applying adequate amounts of nutrients in the rainfed systems of drylands. Crop yield cannot be significantly improved without ensuring stable, fertile soil and soil moisture (Suhas et al., 2011).

Combating soil degradation in semiarid regions through SWC measures can contribute to the maintenance and increase of soil organic matter. The availability of soil organic matter improves soil properties such as water-holding capacity, fertility, and productivity of soils (Koohafkan and Stewart, 2008). Investments in soil fertility improvements of rainfed farms increased rainwater productivity and crop yields by 70 to 120% when both micronutrients and adequate nitrogen and phosphorus were applied (Suhas et al., 2011).

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Improvement of soil organic matter can be initiated by creating permanent cover on the soil to reduce or eliminate runoff and erosion, and to reduce soil surface temperatures that can slow down the decomposition of organic matter. To reduce or reverse soil degradation in dryland, it is also imperative to reduce or avoid tillage practice, which drastically increases the rate of decomposition, and thereby maintain cover on the soil surface in cropping systems (Koohafkan and Stewart, 2008).

To take advantage of retaining surface runoff in farms, various soil organic matter improvement practices may be considered. These include the application of farmyard manure, timely weeding, and the use of mulches that can improve soil water-holding capacity and reduce soil evaporation. In this regard, according to Shulan et al. (2016), wheat straw mulching in China retained more water in the soil and decreased soil evaporation. Additional soil moisture storage of 216 mm was obtained in mulch treatment of 6 ton ha-1 as compared to the control that had only 39 mm.

4.2.3. Practicing Proper Water Management

Considering the fact that water is the prime resource in watershed management (Suhas et al., 2011) in dryland areas with unpredictable and declining rainfall, various types of in-situ and ex-situ water harvesting schemes are required as part of the overall SWC intervention at the watershed level. These schemes improve water availability for multiple purposes, which requires capturing, storing, and diverting seasonal excess runoff with effective water use (water productivity) (Binyam and Desale, 2015). Moreover, these SWC (water harvesting) practices in drylands create favorable conditions for irrigation and other socio-economic activities, providing opportunities for economic benefits for society beyond increasing drought resilience capacities (Koohafkan and Stewart, 2008; Gebremedhin et al., 2019).

In a world where rain-fed agriculture still dominates (80.6%, 94.5%, 96.7% of total arable lands globally, in Africa, and in SSA, respectively) and most of the food is produced from it, irrigation needs to be considered as a reliable supplement to rainfall where soil moisture is insufficient to satisfy the needs of the crops. This is particularly true where there is excessive climate variability, multiple cropping, a need for increased productivity (from 1.5 t ha-1 in rainfed grain yield to about double (3.1 t ha-1) of irrigated grain yield), and the potential of vast rainfed production needs to be unlocked (Suhas et al., 2011). In fact, improving water productivity remains key to unlocking the potential of rainfed agriculture (Suhas et al., 2011).

Integrating water harvesting with supplemental irrigation within a watershed can play a critical role in reducing the risk associated with drought. This implies that investments in water management, along with proper management practices, can serve as an entry point to utilize the potential of agriculture in drylands and sub-Saharan Africa. This approach provides a greater opportunity for improving water availability for supplemental irrigation and sustaining water-storage structures through community participation and institutional support (Elaine et al., 2013). Indeed, supplemental irrigation can make a large difference in crop production, determining whether a crop is grown or not in some dryland circumstances. It is effective in reducing the risk of crop failures and in optimizing productivity in semi-arid regions, contributing to increased yield. In confirmation of this, in Kenya, for instance, the yield of onion increased about sevenfold (from 1.6 t ha-1 to 11.9 t ha-1) (Suhas et al., 2011). In addition to supplementary irrigation, deficit irrigation is considered a promising and effective mitigating strategy to improve crop yield and water productivity (David et al., 2010).

Considering traditional runoff water harvesting and the use of water for supplemental irrigation (spate irrigation) as valuable local experiences, stakeholders need to promote such practices, particularly in the drylands of the world. This is because, through supplementary irrigation, it is possible to bridge dry spells and thereby reduce the risks in rainfed agriculture. Water can best be given when the soil moisture drops to a critical level, which can be determined by measuring the soil moisture on a regular basis and identifying the optimal time for irrigation. Furthermore, promoting supplementary irrigation in rainfed areas would not only contribute to an increase in yield, but it could also enable farmers to decide on the sowing date of the primarily rainfed crops without needing to wait for the often irregular onset of the seasonal rain, and avoid terminal drought. These opportunities, in turn, would create a longer growing season and better yield. According to Binyam and Desale (2015), it is evidenced that supplementary irrigation contributed to a crop yield increase by 20%. An increase of seasonal plant water use by 25 mm could increase the average yields of wheat, maize, and sorghum by 30, 38, and 58 %, respectively (Koohafkan and Stewart, 2008), and on average, 47% of wheat yield in China was dependent on the soil water storage at sowing (Shulan et al., 2016).

At the watershed level, land and water can be managed in an integrated manner, shifting from rainfed to supplemental irrigation using harvested runoff water or recharged groundwater. It would thus be possible to bring additional water onto rainfed fields through SWC interventions, enabling the growth of crops even in places where this was not possible previously (Christopher et al., 2016). In a watershed treated with SWC measures, the dryland water management strategy of controlling runoff through in-situ and ex-situ water harvesting practices is a key task in any dryland cropping system (Koohafkan and Stewart, 2008).

4.2.4. Improving Agricultural Water Productivity

In most drylands, such as those in sub-Saharan Africa, water is a critically scarce resource, and the amount of water available for supplemental irrigation is generally limited. Under such conditions, promoting the efficient application of water is very critical to reduce water losses and increase water use efficiency (Pankaj et al., 2019).

In the face of further desertification, the world must learn and succeed in producing more food with less water (increased water productivity) to cope with the increasing pressures on water resources and the increasing demands for food and fiber. Improved water use efficiency and productivity can contribute to food security through the conservation of water via various types of structures and agronomic management, which can improve water productivity by 50–100% (Suhas et al., 2011). Thus, effective water conservation and saving systems need to be implemented to mitigate droughts while improving in-situ soil moisture conservation for agricultural uses by reducing evaporation and implementing conservation agriculture. Practicing appropriate water management activities with the purpose of producing more crops using less water in both rain-fed and irrigation schemes can contribute to overcoming crop water shortages and improving water productivity (Gebremedhin et al., 2019).

In Sub-Saharan Africa (SSA), most (96%) areas are irrigated using surface flood irrigation methods, which are not very efficient and result in high water losses through seepage and evaporation, with 10-35% losses in unlined canals (Pathak et al., 2009). Hence, water must be used efficiently in these regions in particular by improving irrigation water deliveries through a range of technical and management practices. These include the promotion of drip and sprinkler irrigation, more precise application practices, canal lining or delivery through pipes, and reduced allocations of water to farmers or pricing to influence demand (David et al., 2010). An irrigation system needs to focus on maximizing the evapotranspiration component (productive loss) with added water (supplementary irrigation) while minimizing unproductive losses (such as runoff and deep percolation). Yet, to realize water productivity, understanding soil–crop systems and designing appropriate practices for water conservation and irrigation strategies (supplementary or/and complementary) are crucial (Koohafkan and Stewart, 2008).

Practicing appropriate water management activities with the purpose of producing more crops using less water in both rain-fed and irrigation schemes can contribute to overcoming crop water shortages and improving water productivity. The water-saving and conserving practices include: reducing field irrigation water losses by shifting from surface irrigation schemes to pressurized irrigation systems, from more water-demanding to low water-demanding crops, linking rainfed and irrigated systems (in conjunctive or alternating use of rainfall and irrigation), rainwater harvesting (from watersheds, roofs, and rock surfaces), supplementary irrigation and deficit irrigation, promoting climate-smart technologies such as solar and wind pumping, managing floods, and practicing spate irrigation for augmenting soil moisture and preventing flood damages downstream (Gebremedhin et al., 2019).

In many regions of the world, there are opportunities to increase water productivity in rainfed, irrigated, livestock, and fishery systems by adopting breeding strategies and proven agronomic and water management practices. The SSA and South Asia (with very low yields, extreme poverty, and many poor people highly dependent on agriculture) can be targeted for increasing water productivity. Addressing water productivity in such areas can both reduce the amount of additional water needed for agriculture globally and help to reduce poverty (David et al., 2010). Wherever water appears to be a more limiting factor than land, maximizing water productivity is more important than ever (Suhas et al., 2011). Christopher et al. (2016) confirmed that there are opportunities to improve crop water productivity in drylands by two to four times if technical, resource, and market hurdles can be overcome.

4.3. Third key condition: Assuring proper integration of agricultural inputs

In drylands, low productivity in rainfed systems, water shortage, a degraded and marginal soil resource base, and lack of investment in soil fertility maintenance have marginalized rainfed agriculture and the livelihoods in semiarid regions. Applications of other agricultural inputs and technological advances (such as improved varieties, fertilizers, and pesticides) are generally ineffective. To boost crop production, all agricultural inputs (including soil fertility, high yielding varieties, pesticides, etc.) need to be integrated with water availability (through water harvesting and soil and water conservation). The semiarid tropics, in particular, have high potential for increasing crop yield due to abundant solar radiation. It is evidenced that 70% of grain production comes from intensification through yield increases per unit land area, while the expansion of agricultural areas alone can only contribute to the remaining 30% (Suhas et al., 2011).

Within a treated watershed, practicing a combination of new cultivars and enhanced utilization of water resources can strengthen ecosystem services and increase water efficiency for the cultivation of suitable crops and modified rangelands. These may include the use of organic fertilizers to increase the water-holding capacity of the soil, effective weed control and crop protection against pests and diseases, and more effective use of rainwater (Elaine et al., 2013). An increase in cereal production in developing

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countries may thus be realized through the development of irrigated lands coupled with high yielding varieties (HYVs), improvement of soil- and water-management practices on existing rainfed lands (producing more cereal grains with the same or less amount of water through better water management), water harvesting and water conservation, as well as through increased water-use efficiency of both irrigated and non-irrigated agriculture (Koohafkan and Stewart, 2008).

In a nutshell, successful farming in drylands demands integrated management of soil, water, crops, and plant nutrients. Integrated nutrient and water management options, as well as the use of improved cultivars in semi-arid regions, have significantly increased rainwater productivity and grain yields (Koohafkan and Stewart, 2008; Suhas et al., 2011). However, the success of agricultural development depends on whether its water harvesting and management is economically, environmentally, and socially feasible and sustainable (Koohafkan and Stewart, 2008).

4.4. Fourth key condition: Establishment of a watershed-based scientific (research) and technology (innovation) platform

4.4.1. Access to scientific tools

The lack of sufficient scientific inputs in terms of research (Pankaj et al., 2019) and development is responsible for low productivity in semi-arid regions, in addition to biophysical and social constraints (such as poor infrastructure, inherently low soil fertility, frequent occurrence of drought, severe degradation of the natural resource base, and poor social and institutional networks). To this effect, the application of diverse water management technologies, as well as policies and management strategies to reduce water use, control salinization, maintain ecosystems, and ensure sustainable water use for public water supply, irrigation, and industrial use, are required in drylands (Magaly and Thomas, 2016). Moreover, new scientific tools such as simulation modeling and decision support systems (DST) (Pankaj et al., 2019) for integrating and simulating the effects of soil, crops, weather, and management options, remote sensing (RS), geographical information systems (GIS), global positioning systems (GPS), and information and communication technology (ICT), automatic weather stations (AWS), water balance models, mobile devices, and server technologies for data storage and dissemination can be established to enhance productivity in semi-arid regions through science-led development. Establishing an intelligent watershed information system (IWIS) would help to integrate all these scientific tools (technologies) for efficient management of watersheds through IWSM (Suhas et al., 2011).

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Among other things, the application of scientific tools such as high-resolution remotely sensed data in conjunction with conventional data can provide valuable and reliable inputs for quantifying and mapping watershed area, size, shape, topography, drainage pattern, and landforms for watershed characterization and analysis. These details can be used for quick prioritization of watersheds for the implementation of IWSM based on natural resource constraints and potentials in a watershed, such as natural resource status, socio-economy, biophysical setup, soil erosion proneness, sediment yield, flooding, poverty, etc. Furthermore, research is required to evaluate and improve the performance of IWSM. A baseline study needs to be carried out for comparison with changes due to interventions through IWSM (ibid).

Thus, in implementing the IWSM approach to manage water sustainably in dryland regions, new evaluation methods and the fusion of development and research are required to carry out field measurements, modeling, and remote sensing, and to evaluate water resources and resolve regional and local issues. Moreover, in countries that use salt-affected soils with proximity to water resources, scientific optimization of the use of these soils, determination of their potential, productivity, and suitability for growing different crops, and identifying appropriate integrated management practices are required (Koohafkan and Stewart, 2008).

4.4.2. Coping Strategies and Innovations

Inhabitants of drylands have, in fact, learned how to cope with unreliable rainfall and threats of recurrent drought through surplus water accumulation, shifting cultivation, and nomadism. However, widespread poverty and increased human pressure on the fragile resource base mean these coping strategies are not sufficient in reducing people's vulnerability (IISD, 2003). Fortunately, there is scope for increasing food production through improving inefficient dryland agriculture. It would be a disgrace to disregard the potential to increase food production from dryland agriculture because of the difficulties associated with it. In improving dryland agriculture, innovations may contribute to shortening the food cycle to enhance food production and secure where the consumers are located (Koohafkan and Stewart, 2008).

All of the key conditions discussed above could thus be integrated within IWSM, as shown in Fig 2. Moreover, the IWSM must be evaluated in terms of environmental soundness, economic viability, and social acceptability, considering support from research and educational institutions (Gadisa, 2016). The contributions of IWSM interventions can be evaluated based on various indicators that include: **physical** (biological and physical achievements), **socio-economic** (increased crop yield and fodder production as a result of increased irrigation water, increased women participation, etc.), and **ecological** (increased animal diversity, vegetation cover, groundwater recharge, reduced flooding/surface runoff, etc.).

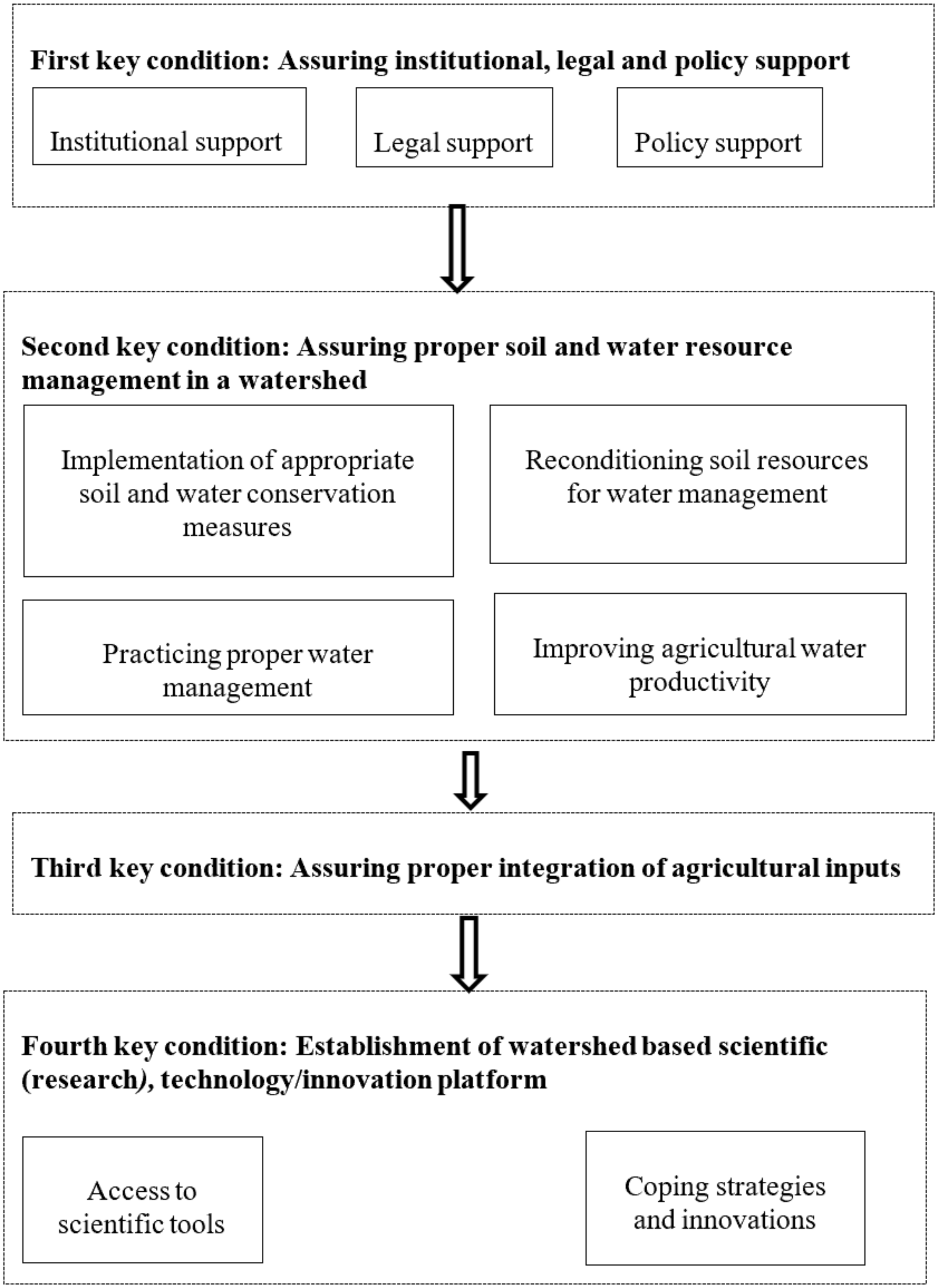

Figure 2. Integration of key conditions in IWSM approach for sustainable water availability and agriculture in semiarid regions

5. Conclusions

The integrated watershed management approach has been applied in various countries around the globe with the intention of preventing and rehabilitating watershed sustainability and improving livelihoods. However, based on literature reviews and personal observations, the achievements are restricted to some soil and water conservation interventions. Various constraints are retarding the success of the approach in the face of all possibilities of conversion from semi-aridity to aridity across the globe. In this study, the focused constraints include poor institutional and policy support, lack of participation, poor planning of soil and water conservation, inappropriate use of technologies, and failure to utilize scientific inputs, as well as lack of capacity building. Thus, for revitalizing the implementation of the IWSM approach, the key conditions that require focus are assuring institutional, legal, and policy support, practicing proper soil and water resource management, securing access to integrated agricultural inputs, and establishing scientific and technology support in a watershed. Amending the approach and integrating all these key conditions in IWSM are crucial for the successful implementation of IWSM in a watershed to realize the sustainability of water availability and agriculture in semi-arid regions in particular. Moreover, the performance of IWSM needs to be evaluated in terms of environmental soundness, economic viability, and social acceptability for the sustainability of the IWSM approach in every watershed in semiarid regions across the globe.

Declaration of Competing Interest

The author declares that there are no competing financial or personal interests that could influence the work reported in this paper.

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