Implications of rainwater harvesting in a river basin management: evidence from the Modder River basin, South Africa

Y. E. Woyessa[1], E. Pretorius[1], P. S. van Heerden[2], M. Hensley[3] & L. D. van Rensburg[3]
[1]*School of Civil Engineering and Built Environment, Central University of Technology, South Africa*
[2]*Consultant: Agricultural extension and general irrigation practice, South Africa*
[3]*Department of Soil, Crop and Climate Sciences, University of the Free State, South Africa*

Abstract

In a new paradigm shift related to integrated water resources management in the context of a river basin, attention is being drawn to consider the upstream and downstream impacts on the various water use entities. The river basin is increasingly acknowledged as the appropriate unit for analysis and management of water resources, especially as water availability becomes the primary constraint to agriculture. The irrigated agriculture in the Modder river basin, in the central South Africa, draws water from river pools and weirs. However, many small-scale farmers rely on rain-fed farming. A few years ago, the ISCW-ARC introduced a rainwater harvesting technique for these farmers, which is reported to have increased crop yield significantly compared to conventional practices. The research questions were: what is the potential expansion of this technique? and; what will be the implications of this practice on the downstream users if applied on a wider scale? A field survey showed that a fairly rapid spread of the application of the technique can be expected within the scope of home yard size, but no significant spread to community gardens and beyond is expected in the short term because of socio-economic constraints such as poverty, and lack of appropriate tools and basic farming skills.
Keywords: rainwater harvesting, river basin, small-scale farmers.

1 Introduction

In a new paradigm shift related to integrated water resources management (IWRM) in the context of a river basin, attention is being drawn to consider the upstream “off-site” influences on the various water use entities, as well as the downstream “off-site” impacts arising from them. Along the path of water flowing in a river basin are many water-related human interventions, including water storage, diversion, distribution, pollution and other associated acts that modify the natural systems. All of these have one common effect that impact on those who live downstream [10].

With the recognition of significant reuse of water, the river basin is increasingly acknowledged as an appropriate unit for analysis and management of water resources, especially as water availability becomes the primary constraint to agriculture. Growing scarcity of good-quality water in most river basins results in intense inter-sectoral competition for water. The efficiency of water use can be seen in a more comprehensive manner if the allocation of water in a basin among various users is considered. Similarly, a more comprehensive analysis is required on the adverse effects of a rapid degradation of the environment and other ecological problems arising from severe competition for water [1].

As countries experience growing water scarcity, water-sector institutions need to be reoriented to cater for the needs of changing supply-demand and quality-quantity relationships and the emerging realities [9]. It is inevitable that irrigated agriculture, the largest water user in many river basins, will be called upon to reassess its water requirements in view of the competition for water from other users. There is now wide acceptance of the necessity to focus on higher-level institutions, generally at the basin level.

The river basin is a geographical unit that defines an area where various users of the basin’s water interact, and where most of them live. A basin perspective helps in the analysis of the interactions among various types of water uses and users, and in the process, it helps in better understanding of the physical, environmental, social and economic influences that impinge on the productivity of agricultural water management. In a basin context, participation of a larger number of stakeholders can be sought, and water resources planning can be more effectively carried out.

An integrated approach to water resources management in a river basin would enhance both productivity and sustainability of natural resource use. This implies that concerns about resources use should transcend short-term “on-site” gains, and should necessarily focus on an environmentally sensitive use of resources including many possible “off-site” implications. The off-site influences on a water use system, as well as the off-site impacts arising from a water use system, can both be systematically studied to identify the factors that affect the performance of the water use system.

The irrigated agriculture in the Modder river basin, central South Africa, draws water from river pools and weirs. However, many of the small-scale farmers rely on rain-fed agriculture for crop production. In the past few years, the Institute for Soil, Climate and Water (ISCW) of the Agricultural Research Council (ARC) has introduced rainwater harvesting techniques to small-scale farmers for crop production [4]. It has been reported that with the use of the technique, called Infield Rainwater Harvesting (IRWH), the surface run-off was reduced to zero and that evaporation from the soil surface was reduced considerably, resulting in a significant increase in crop yield (30 to 50%) compared to conventional practices [3].

Moreover, this practice was also reported to reduce soil loss significantly, which otherwise would run into the river system. The researchers expect that many small-scale farmers in the river basin, with limited access to irrigation water, will be able to adapt this practice for crop production. The research questions were: what is the potential expansion of this technique; what will be the implications of this practice on the downstream of the river basin if used on a wider scale; and what are the crop production and water productivity under on-site and off-site use of runoff water?

The objective of this paper is to present results of a field study on possible expansion of IRWH techniques and the challenges facing farmers in up-scaling the practice at a wider scale. Attempt was also made to highlight possible impact of the IRWH on runoff reduction and implications for crop production and water productivity under on-site and off-site conditions.

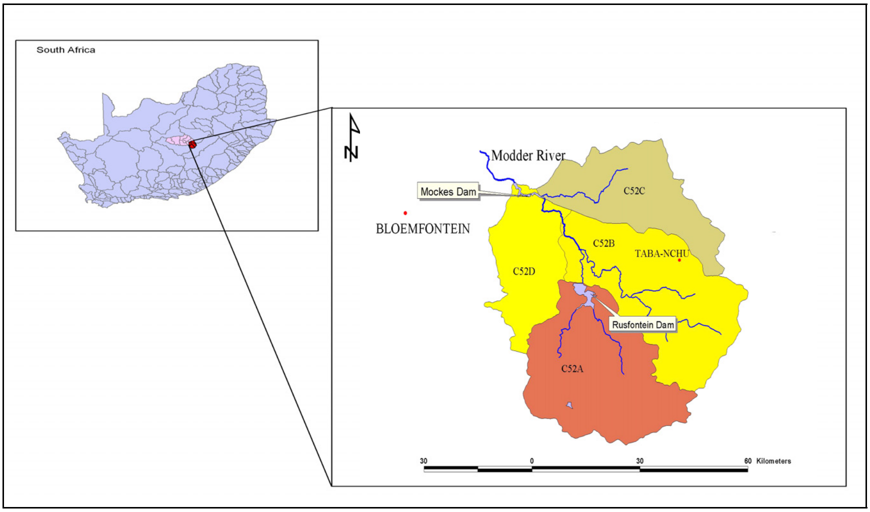

Figure 1: Location map of the study site and delineated sub-catchments in the Upper and the Middle Modder River basin.

2 Material and methods

The Modder River basin is a large basin with a total area of 1.73 million hectares. It is divided into three sub-basins, namely the Upper Modder, the Middle Modder and the Lower Modder. It is located within the Upper Orange

Water Management Area to the east and north of the city of Bloemfontein, central South Africa. Four quaternary catchments, hereafter referred to as sub-catchments, located in the Upper and Middle Modder River basin have been selected for this study (Figure 2). These sub-catchments are: C52A, C52B, C52C and C52D with a total area of 295,766 ha.

To predict the possible expansion of the IRWH, which is depicted in Figure 2, and its effects on runoff generation, one needs to determine the present situation regarding its application and determine the challenges that farmers are facing in the adoption process. This information could then be used as a predictor of future expansion. Wide scale adoption of the technique could have a negative/positive impact on the quantity and quality of water downstream of the river basin if it is applied on all the suitable lands for IRWH. The methodology used in the assessment of the potential expansion of the IRWH was a participatory approach using semi-structured interviews and focus group discussions in order to determine the perceptions and attitudes of the communities regarding the IRWH technique. The survey was conducted on samples of 21 villages that were selected randomly out of 45 villages from communal farming areas. A total of 335 people were involved in this survey exercise.

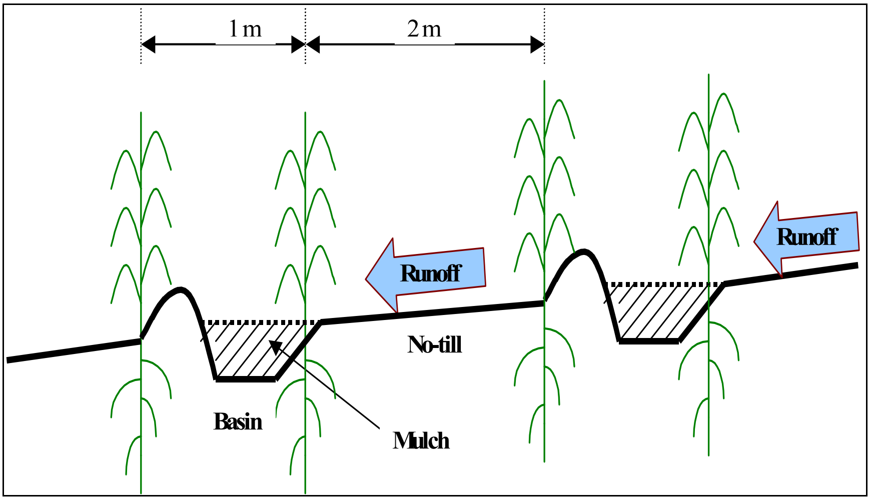

Figure 2: Diagrammatic representation of the Infield Rainwater Harvesting (IRWH) technique (after Hensley *et al.* [4]).

Long-term data on the hydrology of the catchment, such as precipitation and runoff were obtained from a database of surface water resources of South Africa [5]. With the identification of the suitable area of land for IRWH in the study area, based on soil and topographical information, the mean annual runoff was estimated for the whole catchment and the possible impact of IRWH technique on runoff generation was quantified. Comparative analysis of use of runoff water for crop production was made for on-site (upstream) and off-site (downstream) conditions using a water productivity concept [6]. In a broader sense, the productivity of water refers to the benefits derived from a use of water. The expression of water productivity is most often given in terms of mass of produce, or monetary value, per unit amount of water.

3 Results and discussion

3.1 Potential expansion of the IRWH in the communal farming areas

The introduction of the IRWH technique at the present moment is focused on the communal farming areas which are dominated by small-scale farmers with limited access to irrigation water. The portion of the catchment occupied by the communal farming area constitutes about 35% of the total area of the study site.

The IRWH technology was rolled out to communities in the Thaba-Nchu area during phase II of the ARC-ISCW water harvesting program. Phase I concentrated on the scientific development and testing of the technique against conventional tillage using on-station facilities at Glen Agricultural Institute and on farmers fields. Summer crop yields were between 30 and 50 % higher on the IRWH plots than conventional tillage [3]. During phase II much attention was given to the understanding of the water related processes such as runoff, evaporation, soil water storage, mulching, etc. by using an Interactive Physical Scale model [11].

The result of a field survey in this project showed that the technique is expanding fast at home yard level. However, presently there is only a limited expansion to community croplands because of socio-economic constraints, such as poverty, lack of appropriate tools, and lack of basic farming skill. A large proportion (86%) of the small-scale farmers responded that this technique contributes to household food security. However, lack of market and necessary farming skill has been repeatedly mentioned by the respondents. Ninety percent (90%) of the respondents indicated that they applied the technique in their home garden, while eight percent planted in both community and home gardens and two percent in a community garden only.

It appears that a fairly rapid spread of the application of IRWH techniques can be expected within the scope of home yard size but no significant spread to community gardens and beyond is expected in the short term because of socio-economic constraints discussed above. The support services provided by the ARC-ISCW extension group do have a positive influence on future expansion. However, the high levels of poverty and labour requirement for the preparation the plots are some of the limitation for further expansion.

3.2 Estimation of runoff and impact of IRWH technique

In the study area there are two dams, namely Rusfontein Dam and Mockes Dam, which are used to store water for the supply to the cities of Bloemfontein, Botshabello and Thaba Nchu, as well as for supply of irrigation water for the downstream commercial farmers. The runoff generated from C52A (see Fig.1) is captured by the Rusfontein Dam. The remaining sub-catchments, such as C52B, C52C and C52D drain into the Mockes Dam. Gauging stations placed at the vicinity of the two Dams measure the incoming runoff water into the Dams. These data are available for Rusfontein Dam for 36 years giving the total mean annual runoff coming into the Dam from a catchment area of 93,671 ha (i.e., area of C52A) as 34 million cubic meters or 36.3 mm [5]. The mean annual precipitation for the study area is 550 mm. Based on these values the mean runoff coefficient was calculated to be 6.6%. Using this information, runoff amount draining into the Mockes Dam was estimated (Table 1).

The magnitude of the effect of the IRWH on the inflow of runoff into the Dams depends on the total area suitable for this technique. The summaries of runoff generation from the catchment and the possible effect of IRWH on the annual inflow to the Dams are given in Table 1. Table 1 shows possible scenarios of what may be expected if all the suitable land in the catchment is put under cultivation using the IRWH technique. The area of land suitable for IRWH technique is estimated to be 27% of the total area of the catchment. If all runoff from this portion of the catchment is retained for on-site use for crop production, it is estimated that it will reduce the mean annual runoff from 107 to 78 million cubic meters. It should be noted that, in this part of the country, mean annual evaporation (Class A pan) is 2198 mm [3], which can cause a tremendous amount of water loss from storage reservoirs. For instance, it is estimated that Rusfontein Dam, with storage surface area 1158.5 ha, loses 2.5 million cubic meters of water annually through evaporation. In this context, the on-site use of rainwater at upstream level for food production may contribute to the reduction of non-productive water loss due to evaporation.

Table 1: Possible impact of IRWH on the inflow of runoff into the Dams.

Parameters	**Values**
Mean annual precipitation (mm)	550
Mean annual runoff draining into Rusfontein Dam (m^3)	34×10^6
Mean annual runoff draining into Mockes Dam (m^3)	73.4×10^6
Area (ha) of catchment draining into Rusfontein Dam	93,671
Area (ha) of catchment draining into Mockes Dam	202,095
Runoff coefficient (%)	6.6
Total area of the catchment (ha)	295,766
Total suitable area for the IRWH (ha)	80,667
Suitable area as % of the total area of the catchment	27
Mean annual runoff from the total area (m^3)	107×10^6
Mean annual runoff retained in the IRWH area (m^3)	29×10^6

However, the assumption of the scenario of all the suitable land for IRWH being put under cultivation using the technique should be seen in relation to the following factors. Firstly, the current form of the IRWH technique has been designed for implementation using hand labour, and therefore only suitable for the relatively small areas expected to be developed initially by communal farmers living in the catchment. The estimated area of suitable land for IRWH inhabited by communal farmers is 15,000 ha. At present IRWH is employed almost exclusively by the communal farmers in their backyard gardens. The rate of expansion into the 15,000 ha of communal cropland is expected to be determined by the extent to which certain constraints can be overcome. Secondly, research is currently being planned to mechanize the IRWH technique in order to make it suitable for commercial production. If this proves to be successful, expansion would probably be accelerated and the technique may then be employed even by the commercial farmers on the remaining suitable land for IRWH in the catchment.

So, it appears that, under present condition, expansion of the technique into the whole suitable area is far from imminent. There is, therefore, no reason to believe that the water balance of the Modder River will soon be affected significantly as a result of the expansion of IRWH technique. However, it is useful to study the possible impact of the different scenarios of use of this runoff water, on-site versus off-site, in relation to the comparative advantage in terms of yield and water productivity. These are discussed under the following section.

3.3 Crop production scenarios and water productivity: on-site versus off-site conditions

Water productivity in rainfed agriculture will have to increase dramatically over the next generations if food production is to keep pace with the population growth [8]. In sub-Saharan Africa, over 60% of the population depends on rainfed agriculture, generating about 30-40% of the country GDP [12]. Rainfed agriculture is practiced on approximately 95% of agricultural land, with only 5% under irrigation [8]. This shows that rainfed agriculture will remain the dominant source of food production for the foreseeable future.

In many parts of the water scarce tropical countries, yields from rainfed agriculture are low, oscillating around 1 t/ha [7]. However, many researchers suggest that the low productivity in rainfed agriculture is more due to sub-optimal performance related to management aspects than to low physical potential. For instance, Bennie *et al.* [2] reported that in arid and semi-arid areas between 60% and 85% of the rainfall evaporates from the soil surface before it could make any contribution to the production. With the use of the IRWH technique, it is reported that evaporation has been reduced significantly, contributing to the increase in yield on average 30 to 50% compared to conventional farming [3]. On the other hand, it has been shown by several hydrological studies that upstream shifts in water flow partitioning may result in complex and unexpected downstream effects, both negative and positive, in terms of water quantity and quality, e.g. shifting of flow partitioning from surface to sub-surface runoff or increasing consumptive use [8].

In this study, comparative analysis of use of runoff water for crop production was made for on-site and off-site conditions using a water productivity concept [6]. In a broader sense, the productivity of water refers to the benefits derived from a use of water. The expression of water productivity is most often given in terms of mass of produce, or monetary value, per unit amount of water.

In the study area, farmers grow a wide variety of crops, such as maize and several types of vegetables, namely beetroot, pumpkin, spinach, etc. Maize is the main staple crop in the area in particular and in the whole of South Africa in general. Thus, the water productivity analysis was done for maize crop. The procedure in this exercise is based on the estimation of runoff from the catchment given in Table 1, based on which a comparative analysis and the water productivity estimation were made for two scenarios: (1) on-site use of this runoff for maize production using the IRWH technique; and (2) off-site use of this runoff to grow maize crop under full irrigation. This was based on the total water requirement of maize crop, which is 487 mm. It was further assumed that runoff storage loss and conveyance loss from where it is stored to the downstream use point is 35%, based on the current practice of the DWAF. The result is given in Table 2.

Table 2: Water productivity for the two water use scenarios for maize crop production.

Parameters	**Values**	
Total suitable area of land for IRWH (ha)	80,667	
Mean annual runoff retained by IRWH (m^3)	29×10^6	
Irrigation water requirement of maize (m^3/ha)	4870	
Estimated irrigation efficiency for Centre Pivots (%)	75*	
Storage and conveyance efficiency (%)	65*	
Actual runoff amount reaching crop for irrigation	14.14×10^6	
Total irrigable area using this runoff (ha)	2,903	
Expected maize production at 10t/ha under irrigation	29,030	
Mean maize yield using conventional farming (t/ha)	1	
Average maize yield increase due to IRWH (%)	40	
Expected production increase using IRWH (t)	32,267	
Total expected production using IRWH technique (t)	112,934	
Water productivity	**Irrigation**	**IRWH**
Water productivity (kg/mm)	10.0	11.1

*The efficiency values are estimated based on the current irrigation practice in the area.

As shown Table 2, the water productivity was calculated for two water use scenarios, namely for irrigation farming and for farming using the IRWH technique. The comparison of the two production scenarios was based on the assumption that the amount of runoff generated upstream will be used for irrigation of maize downstream with no conjunctive use of rainfall. This assumption was made for the purpose of quantifying the value of water in terms of crop production under the two conditions. The water productivity for IRWH practice was calculated based on the amount of yield increase resulting from the amount of runoff water conserved using IRWH technique.

As it can be observed in Table 2, the water productivity value is slightly higher for IRWH than for irrigation farming when total runoff is used to compute the water productivity for irrigation farming (i.e., the 1st condition). This illustrates that it is possible to increase yield and production, and attain increased efficiency by using rainwater harvesting techniques. It also shows how a significant increase in total production can be obtained under dryland farming if rainwater is conserved in the soil to supplement the crop water requirement at critical crop growth periods.

In the study area, it has been reported that crop production under dryland and conventional farming is very marginal because of relatively low and erratic rainfall [4]. Thus, the use of rainwater harvesting presents an ample opportunity for the small-scale farmers who do not have access to irrigation water. This, however, requires a concerted effort from the part of the Department of Agriculture and other NGOs in the area in the promotion of the technique and skill development of farmers for the sustainability of the system.

4 Conclusion

The ultimate goal of water resources policy in a river basin management is to increase the beneficial utilization of water through reduction of non-beneficial evaporation and water pollution. Rainwater harvesting coupled with appropriate farming practices can contribute towards achieving the goal of increasing the beneficial use of water in a river basin management.

The IRWH technique introduced to the small-scale communal farmers in the Modder River basin is one such practice that is reported to increase yields under dryland crop production compared to conventional method and hence increases the water productivity. The contribution of this practice towards the household food security for the small-scale farmers, who do not have access to irrigation water, is significant if farmers are willing and capable to expand it. However, the challenges faced by these farmers in the adoption of the IRWH technique should be addressed by the concerned governmental departments and NGOs operating in the area.

Runoff estimation at the catchment level showed that up-scaling of the IRWH technique may not have a significant impact on mean annual runoff flowing into the Dams due to limited suitable area available for such practice. However, it would be worthwhile to generate different scenarios using appropriate hydrological modeling tools, which was not possible in this study due to compatibility problems between the different softwares available to us.

Acknowledgments

This report contributes to the Comprehensive Assessment of Water Management in Agriculture, and was supported through grants to the assessment from the governments of Netherlands and Switzerland.

References

[1] Bandaragoda, D. J., A Framework for Institutional Analysis for Water-Resources Management in a River Basin Context. In D.J. BryanBruns, and M.S. Bandaragoda (eds), *Proceedings of the Regional Workshop on*

Integrated Water Resources Management in a River-Basin Context, Malang, Indonesia, 2001.

[2] Bennie, A.T.P., Hofman, J.E., Coetzee, M.J. & Very, H.S. Storage and utilization of rain water in soils for stabilizing crop production in semi-arid areas. (African.) *Water Research Commission Report* No. 227/1/94. Water Research Commission, Pretoria, 1994.

[3] Botha, J.J., Van Rensburg, L.D., Anderson, J.J., Hensley, M., Machelli, M.S., Van Staden, P.P., Kundhlande, G., Groenewald, D.G. & Baiphethi, M.N., Water conservation techniques on small plots in semi-arid areas to enhance rainfall use efficiency, food security, and sustainable crop production. *Water Research Commission Report* No 1176/1/03. Water Research Commission, Pretoria, 2003.

[4] Hensley, M., Botha, J.J., Anderson, J.J. Van Staden, P.P. & du Toit, A., Optimizing rainfall use efficiency for developing farmers with limited access to irrigation water. *Water Research Commission Report* No. 878/1/00. Water Research Commission, Pretoria, 2000.

[5] Midgley, D.C., Pitman, W.V. & Middleton, B.J. Surface water resources of South Africa. Volume II Appendices. *Water Research Commission Report* No 298/2.1/94. Water Research Commission, Pretoria, 1994.

[6] Molden, D., Murray-Rust, H., Sakthivadivel, R. & Makin, I., A., Water productivity framework for understanding and action. *Water productivity in agriculture: limits and opportunities for improvement*, eds. J.W. Kijne, R. Barker & D. Molden, CAB International, pp 1-18, 2003.

[7] Rockström, J., Green water security for the food makers of tomorrow: windows of opportunity in drought prone savannahs. *Water Sci. Technol.* **43**, pp 71-78, 2001.

[8] Rockström, J., Barron, J. & Fox, P., Rainwater management for increased productivity among smallholder farmers in drought prone environments. *Physics and Chemistry of the Earth*, **27**, pp 949-959, 2002.

[9] Saleth, M. R. & Ariel Dinar, *Water challenge and institutional response: A cross-country perspective.* Policy Research Working Paper 2045. Washington D.C., The World Bank, 1999.

[10] Sunaryo, T.M., Integrated Water Resources Management in a River-Basin Context: The Brantas River Basin, Indonesia. *In*, *Proceedings of the Regional Workshop on Integrated Water Resources Management in a River-Basin Context*, eds. D.J. BryanBruns, & M.S. Bandaragoda, Malang, Indonesia, 2001.

[11] Van Rensburg, L.D., Groenewald, D.C. Botha, J.J., Anderson, J.J., van Staden, P.P., Kundhlande, G., The development and evaluation of a physical model for the communication of new crop production techniques to communal farmers. *Proceedings of a workshop on water conservation technologies for sustainable dryland agriculture in sub-Saharan Africa*, eds. D. Beukes, M. de Viliers, S. Makhize, H. Sally & L.D. van Rensburg, Agricultural Research Council, Pretoria, 2003.

[12] World Bank, World Development Report 1997. World Bank, Washington, DC. 1997.