India's water balance and evapotranspiration

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Water balance is a useful hydrologic tool. Recent literature has seen some studies on India's water budget, which show that evapotranspiration estimate for India is much lower than what may be expected given the India's climate and land use. This note attempts to find an answer to this puzzle and suggests how it can be resolved.

Water balance is a useful tool to understand the hydrologic behaviour of a study area. It also enables one to get an assessment of the quality of the data and detect discrepancies. Water balance can be carried out for a small area, e.g. a plot of a few square metres in area to a large continent of millions of square kilometres. The time of analysis can vary from a second to a year or more.

When analysing the water balance data, one must carefully check that the magnitudes of the different terms are of the right order. Relative magnitudes of the different terms should also be in the right proportion. A comparison with the data of hydro-meteorologically similar areas will indicate whether there is any discrepancy in some terms or not.

India's water balance has been discussed, among others by Gupta and Deshpande[1], Kumar *et al.*[2] and Garg and Hassan[3]. These analyses were based on estimates of water-balance components presented in the various documents of the Government of India. The National Commission for Integrated Water Resources Development (NCIWRD) prepared a comprehensive report on water resources development in India[4], which gave data on some components of water balance for the country.

Water balance for India

For a large country like India, water balance equation for a water year can be stated as:

$$\text{Precipitation} = \text{streamflow} + \text{groundwater recharge} + \text{evapotranspiration} + \text{error}, \quad (1)$$

or

$$\text{PPT} = \text{SF} + \text{GW} + \text{ET} + \text{Err}. \quad (2)$$

Normally values of PPT, SF, GW and ET are computed for the study area and put in the equation. Ideally, Err should be zero, but practically it is not. The magnitude of Err may show the discrepancy in various components, but in some cases positive error in a few of them may cancel negative error in others.

If eq. (1) is applied for a water year, it may be assumed that there is no change in soil moisture. When applying the water balance equation to a large area, it is often helpful to sub-divide the area. Of course, it must be ensured that each component, say, streamflow has been correctly estimated for each sub-area.

A difficulty arises when independent measurements of all the components of the water balance equation are not available. The present note is concerned with this situation which arises because the network of stations for estimation of ET in India is sparse and inadequate for reliable spatial averaging. Due to this reason, ET is frequently estimated by eq. (1), by using measured/estimated values of PPT, SF and GW, and assuming Err = 0. The reasonability of the estimated ET value can be checked by comparing it with estimates from hydro-meteorologically similar areas.

We now discuss the components of water balance for India.

Precipitation

According to the Planning Commission[5], the average annual precipitation for India is 1170 mm. With a geographical area of 3.28 million sq. km, this implies a total input of water for the country as 3.28×10^6 sq. km $\times$ 1170 mm $\cong$ 3838 cubic km. However, in the literature, e.g. Gupta and Deshpande[1], Planning Commission[5], the total input of water is taken as 4000 cubic km which is assumed to be a rounded-off figure.

Streamflow

The NCIWRD[4] report gives average annual yield of the different Indian river basins. For the country as a whole, the average annual yield of all the river basins is 1953 billion cubic metres (BCM).

Groundwater

According to the Central Ground Water Board (CGWB)[6], the annual replenishable groundwater resources for the country are 433 BCM. CGWB[6] has also quantified basin-wise and state-wise annual replenishable groundwater resources.

Evapotranspiration

ET is defined by the US Geological Survey (http://ga.water.usgs.gov) as the water lost to the atmosphere from the ground surface, evaporation from the capillary fringe of the groundwater table, and the transpiration of groundwater by plants whose roots tap the capillary fringe of the groundwater table.

With the known values of three variables, eq. (1) was applied to compute ET for the country, and the estimates are

Table 1. Annual water balance for India

Component	Volume (BCM)	Precipitation (%)
Precipitation	3838–4000	100
Streamflow	1953	50.1–48.8
Groundwater	433	11.3–10.8
Evapotranspiration	3838 – (1953 + 433) = 1452 4000 – (1953 + 433) = 1614	1452/3838 = 37.8 1614/4000 = 40.3

Table 2. Average annual evapotranspiration (ET) as percentage of average annual precipitation for some regions of the world

Region	Area (10^6 sq. km)	ET only (%)	ET + infiltration (%)	Reference
World's land	148.9		60.5–66.4 (3 estimates)	Shiklomanov[11]
Australia	7.66	90	–	Australian Water Resources (2005)[7]
Amazon basin	6.2	59.4–82.1 (four estimates)	–	Marengo[8]
La Plata basin South America	3.2	–	73.2 (1951–1970) 67.7 (1980–1999)	Berery and Barros (2002)[7]
France	0.55	62.0	82.8	Institut Francais de L Environment (2004)[7]
California	0.41	69.8		Department of Water Resources[9]
USA	9.16	70		Leopold (1974)[7]
India	3.28	69.5	74.5	Jain *et al.*[10]
India	3.28	40	51.3	Planning Commission[5]

Source: Narasimhan[7].

Table 3. Water balance for select basins

Variable/component	Narmada	Godavari	Cauvery	Krishna	Ganga	Indus	Brahmaputra
Area (sq. km)	98,796	312,812	81,155	258,948	861,452	321,289	194,413
Precipitation (mm)	1,109	1107	1032	838	1051	1097	2589
Precipitation (BCM)	109.6	346.3	83.8	217	905.4	352.5	503.4
Streamflow (BCM)	45.64	110.54	21.36	69.81	525.02	73.31	629.05
Groundwater (BCM)	10.83	40.65	12.30	26.41	171	26.49	26.55
Evapotranspiration (BCM)	53.13	195.11	50.14	120.8	209.4	252.7	–152.2
Evapotranspiration (%)	48.5	56.3	59.8	55.65	23.1	71.7	–

shown in Table 1. Note that it is assumed here that Err is zero. Thus the value of ET is 1452 or 1614 BCM and these values are about 37.8–40.4% of the precipitation.

If estimates of India's ET from other sources significantly differ from this estimate of about 40%, then such a discrepancy should merit careful examination and necessary correction.

Measurement and estimates of ET

ET data are an important input in water budgets at basin, sub-basin and project levels. In the field, ET can be measured by lysimeters, but these are difficult and expensive to operate and maintain. Long-term lysimeter data are present at a few locations in India. Dam-operating authorities estimate evaporation from reservoirs using pan evaporimeters. However, these estimates are generally not published.

A comparison of annual and seasonal magnitude of ET obtained from direct measurements and empirical estimates in a large number of locations would help in correctly estimating ET for the country and determining the reliability of the estimates. Despite the importance, the present availability of ET data for the country is grossly inadequate.

ET in different regions of the world

ET varies with space and time depending on land cover, precipitation (its intensity and amount), and other climatic variables. Hence, ET will have large year-to-year variations, mainly depending on whether precipitation for a given year is above or below normal. Narasimhan[7] critically examined the estimates of ET for India obtained by applying the water-balance equation and compared them with published values for six regions of the world with varying areal extent, climatic regimes and landscape characteristics. Table 2 gives the data compiled by him along with their sources. It can be noted that the estimates for ET vary between 59.4% and 90%.

Marengo[8] and the Department of Water Resources[9] provide estimates for temporal variation of ET for the Amazon basin and for the state of California respectively. Narasimhan[7] compiled their findings and has shown that between wet and dry years, ET varies from 65.7% to 79% for the Amazon basin and 63.4% to 90% for California.

Based on the estimates of range of ET for the areas which are hydrometeorologically similar to India, Narasimhan[7] argued that ET for India of around 40% of the precipitation is a significant underestimation. He questioned the reliability of these estimations and opined that ET for India must be significantly larger than 40%.

This note has attempted to look at this puzzle and find an explanation to the discrepancy by using data pertaining to water balance for select Indian basins.

Water balance for select basins of India

Table 3 presents water balance for select Indian basins. Among these, three are transboundary basins which have substantial exchange of surface flow across the national borders and some exchange through groundwater. Four basins have been picked up from Central and South India. Table 3 also gives the area of each river basin, depth and volume of precipitation, streamflow and groundwater. ET has been estimated by using eq. (1) and

Table 4. Evapotranspiration in Indian basins, excluding Indus, Ganga and Brahmaputra

Component	Volume (BCM)	Percentage
Precipitation (PPT)	4000 – 352.5 – 905.4 – 503.4 = 2238.7	100
Streamflow (SF)	1953 – 73.31 – 629.05 – 525.02 = 725.62	32.4
Groundwater (GW)	432 – 26.49 – 26.55 – 171 = 207.96	9.3
Evapotranspiration (ET)	= PPT – SF – GW = 2238.7 – 725.62 – 207.96 = 1305.12	58.3

Table 5. Evapotranspiration in Indus, Ganga and Brahmaputra basins

Basin	Precipitation (BCM)	Streamflow (BCM)	Groundwater (BCM)	Evapotranspiration (BCM)
Ganga	905.4	525.02 (58)	170.99 (19)	209.4 (23)
Indus	352.5	73.31 (20.8)	26.49 (7.5)	252.7 (71.7)
Brahmaputra	503.4	629.05 (1.25)	26.55 (5.3)	–152.2 (–)
Combined	1761.3	1227.38 (69.7)	224.03 (12.7)	309.9 (17.6)

Numbers in brackets are percentages of precipitation.

is given in terms of volume as well as percentage.

It can be seen that for Narmada, Godavari, Cauvery and Krishna basins, ET percentage varies between 48.5 and 59.8. For these basins, overall ET value is 58.3% (Table 4). Note that this value is very much in the range hypothesized for India by Narasimhan[7].

Table 5 presents estimates of ET for Indus, Ganga and Brahmaputra basins. For these transboundary basins, ET is 23.1% of precipitation for Ganga and 71.7% for Indus basins. For Brahmaputra basin, streamflow volume is more than the volume of precipitation, which clearly shows that something is wrong with the data or the assumptions. For these basins, overall ET is 17.6%.

ET values for the Ganga and Brahmaputra basins appear to be unreasonable because these transboundary basins have significant exchange of flow with the neighbouring countries by surface and subsurface routes. The streamflow data used in water-balance computations pertain to the discharges at the terminal site of the basin in India, and this includes the flow entering India from other countries. But the catchment of the rivers in these countries, precipitation and groundwater recharge are not considered. Since Indus, Ganga and Brahmaputra rivers bring in large quantities of flow that has been generated beyond the borders, it would be necessary in ET computations to consider only that part of the flow which has been generated in the Indian portion of the catchment, since all other water-balance components pertain only to the catchment area in India.

A difficulty in computing water balance for these basins is that the flow data are classified and are not easily available. It is doubtful if all important tributaries are gauged at the border.

Discussion

It is noted that there is inconsistency in the water-balance components of the three transboundary basins of India. As a consequence, the estimated value of ET for these basins appears to be much less than the expected values.

Total precipitation in the Indus, Ganga and Brahmaputra basins is 1761.3 BCM. Assuming that ET for these basins is about 60% of precipitation (about the same as in the remaining basins of India), water lost as ET would be around 1056.8 BCM. This means that the SF + GW component for these basins would be 1761 – 1057 = 704 BCM. In general, utilizable water is less than the available quantity. It may be highlighted that according to NCIWRD[4], the utilizable SF + GW for these basins is 496.5 BCM, but if there is some discrepancy in the data, the utilizable water may be lesser. Thus there is need for a closer examination of the data for the basins of Indus, Ganga and Brahmaputra. A significant decline in the estimates of utilizable water in these basins would imply that the present water use in these three basins is already close to their potential and India may be closer to water scarcity.

Concluding remarks

Water-balance data have multiple uses: consistency checks and quality control of the data; planning, design and management of projects; making future projections, and formulating policy for water management and disaster mitigation. A closer look at the water balance for India shows that there are some discrepancies in the estimates of ET.

Discrepancy in water balance for India arises because the Indus, Ganga and Brahmaputra rivers and their tributaries bring in large flow to the Indian portion from across the border. Mean annual flow values for these basins include this flow, but precipitation, groundwater and ET for these areas are not included in the water balance. This results in low estimates of ET for these basins, and hence the overall estimates of ET for India are low. To correctly estimate ET for these basins, and for the country, it would be necessary that the water balance for these basins is carefully examined and exchange of water by all routes is properly accounted for.

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Strengthening ethics of ethics committees in India

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It is often said that the ethics committees (ECs) in India are mushrooming in numbers, but not all are functioning properly. Chatterjee[1] referred to the existence of less than 40 ethics committees that function properly in India. There are only two institutional ethics committees in the country (Ethics Committees of Seth G. S. Medical College and Tata Memorial Hospital in Mumbai) accredited by the Forum for Ethical Review Committees in the Asian and Western Pacific Region (FERCAP) under its Strategic Initiative for Developing Capacity in Ethical Review (SIDCER) recognition programme[2]. Recently, the Indian Council of Medical Research (ICMR), New Delhi, in collaboration with FERCAP organized a symposium on human subject protection course followed by a training programme on developing standard operating procedures for ethics committee members at the Sanjay Gandhi Post Graduate Institute of Medical Sciences (SGPGIMS), Lucknow, where 13 ECs participated, indicating a rise in their number. This exercise was undertaken as a part of the programme to accord recognition to the ethics committee at SGPGIMS and questions raised were related to how its functioning can be monitored, whether the selection of members was done in conformity with the ICMR guidelines[3], and whether it was monitoring clinical research projects efficiently. It is being gradually realized that unless proper monitoring is done an EC will not ensure compliance of an approved protocol. While questions are being raised about the functioning of ECs in developed countries[4] and reforms are being proposed[5], it is time for introspection in developing countries as well. This has been further necessitated by a recent report on the criticism of ethics surrounding the human papillomavirus (HPV) vaccine project[6].

ICMR guidelines consider competence and independence as the hallmarks of institutional ethics committees (IECs). The competence relates to expertise in the committee and independence is concerned with freedom accorded to take decision without any coercion. In India, there is no structured information available on these aspects of ECs. The European Forum for Good Clinical Practice (EFGCP) has brought out a report on research ECs in Australia, Brazil, Canada, China, India, Japan and USA, now available on its website[7]. This report was uploaded in July 2010 and addresses information regarding 12 carefully planned questions on the functioning of ECs in the countries mentioned above. There are two major aspects of ECs, namely constitution and mode of functioning. In India, there is no collective information about ECs in the public domain. A recent report from Clinical Trial Registry India (CTRI) revealed that there is lack of awareness on regulatory processes, especially related to ethical review and many institutes have no ECs[8]. ICMR, in collaboration with the World Health Organization, conducted a survey of ongoing clinical research/trials in 71 institutes in 2002. Thirty-six institutes responded and each reported having IECs and 24 also had separate scientific review committees. Standard operating procedures were in place for review procedures in 23 IECs and 14 claimed that they had trained members in research bioethics[9]. The expertise requires having members with training in identifying and resolving the ethical issues that are becoming complex with newer scientific advances. Therefore, there is a need to define training level for such labelling of ethics expertise. The following questions remain unanswered and need immediate attention in the light of the controversy surrounding ethical issues of the HPV vaccine study: what should be the minimal expertise level? Is certification by attending an ethics workshop sufficient for complexities encountered in ethics review or continued updating is essential? How does one decide on updating modalities? Are such facilities available to EC members easily and do they have enough interest to devote their time?

The Drugs Controller General of India (DCGI) has stake in adequate EC functioning and depends primarily on ECs for implementing ethical standards in clinical trials. Schedule Y implemented by the DCGI is proposed to be further amended – with the introduction of Schedule Y3, wherein research ECs overseeing clinical trials in the country will have to be registered with the office of the DCGI, as also reported in the EFGCP report (www.efgcp.eu).

Streamlining the ethics review

Each country should have its own mechanism to improve the functioning of ECs, and the institutes involved in health research must send a strong message to