Validity of the application of open dug well sanitary survey methodology in the development of a water safety plan in the Maldives islands

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Abstract

As practised in the remote Maldives islands, groundwater exploitation using open dug wells with on-site sanitation systems causes major microbial contamination of well water. Surveys show that 75% of the Maldives population currently rely on rainwater tanks for drinking water. Global climatic change causes prolonged drought periods and extensive rainfall events causing flooding. In addition to rainwater storage tanks, the very limited land area makes the utilisation of the natural underground reservoir an essential water source for the remote Maldives islands. Therefore, it becomes vital to protect the groundwater quality in these islands.

Using methods published by World Health Organisation (WHO) for combined hazard identification and faecal contamination, a surveillance study of open dug wells was carried out in six selected islands of the Maldives. The aims were to assess the current risks and sustainability of the open dug wells in the study areas with respect to sanitation related health issues. The field study involved systematically collecting data about sanitary hazards in the neighbourhood of wells and well water quality, including thermo-tolerant faecal coliform counts. The results showed that the great majority (83%) of wells were, as expected, faecally contaminated. However, the expected benefit of using combined sanitary survey and faecal contamination level assessment to prioritize specific remedial actions to improve the microbial quality of well water was not realized in this study, in contrast to earlier published studies. The principal reasons for this methodological failure are:

1. *the geological setting of the Maldives is extremely vulnerable overall, particularly since there is effectively no soil layer*

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2. *in the absence of a soil layer septic tanks are constructed partly within the shallow aquifer resulting in direct faecal contamination of the aquifer by tank effluents*
3. *basic rules of construction of septic tanks e.g. water tight tank linings and tile field construction for effluent treatment, are ignored, compounding the problem of direct faecal contamination*
4. *the close proximity of septic tank effluents to dug wells occurs almost everywhere, and overwhelms the contribution of all other potential hazards.*

Irrespective of the impact of climate change on sea level and rainfall patterns, it is concluded that current on-site sanitation practices are unsustainable. A major programme of disciplined construction of septic tanks with careful attention to tile field design would be required to address the problem of faecal contamination of the aquifer.

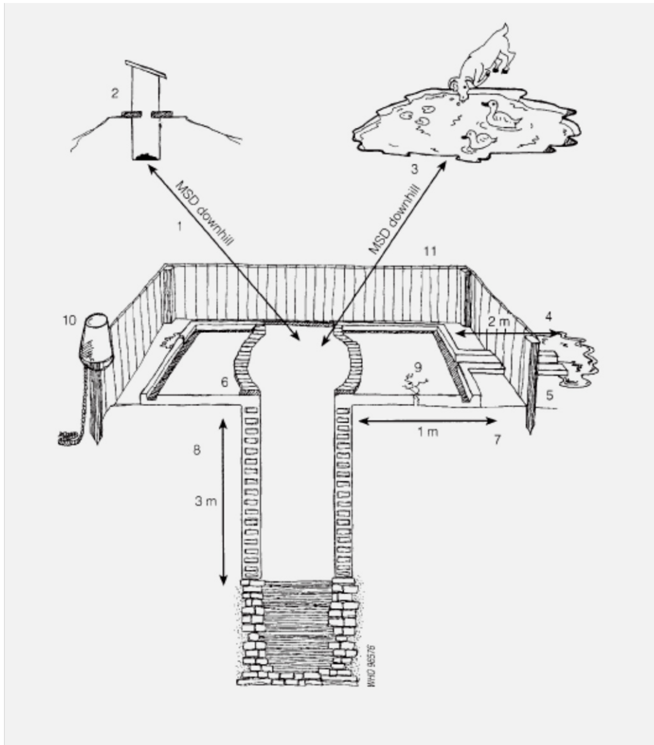
Keywords: groundwater, on-site sanitation, sanitary survey, well and the well head area, faecal coliforms.

1 Introduction

Water and sanitation issues are significant in Asia. 63% of the global population which is not served with improved water supply; and 80% of the population not served with improved sanitation is located in Asia [3]. Water, sanitation and hygiene are interrelated issues. Therefore the Asian population faces a very high health risk. Water and sanitation interventions help to increase public health. Issues relating water quality and sanitation practices have long been discussed and a variety of solutions have been proposed. Techniques used in developed countries for safe sanitation and sustainable water supply are often inappropriate for developing countries mainly because the latter lack adequate technological and financial resources. Developing countries require simple yet robust measures for achieving safe water and sanitation coverage.

The WHO [4] Water Safety Plan (WSP) describes the approach of complete risk assessment and risk management of the water supply system from the catchment level to the end user level, to assure the safety of a drinking water supply. As mentioned earlier, developing countries often cannot afford comprehensive studies due to lack of financial and technical support. Hence the published [2, 5] combined risk analysis of sanitary hazards and faecal coliform (FC) grades is potentially, a useful tool in the context of developing countries in the development of WSP for water supplies, which are often dug wells in the case of South Asia.

Lloyd and Helmer [5] developed sanitary survey forms, which combined a questionnaire and graphical presentation (Figure 1) of the well and the well head area, for water supplies to identify and graphically present the observable potential sanitary hazards present in the well and the well head area. Each survey form has a list of questions, if answered ‘yes’, by the sanitary survey officer, will indicate the presence of particular sanitary hazard at the wellhead area. The total number of observed sanitary hazards (termed as Sanitary Hazard Score, SHS)



I Type of facility OPEN DUG WELL

1. General information: Health centre ....
   Village ....
2. Code no.—Address ....
3. Water authority/community representative signature ....
4. Date of visit ....
5. Water sample taken?....... Sample no. .... Thermotolerant coliform grade ....

II Specific diagnostic information for assessment	**Risk**
1. Is there a latrine within 10 m of the well?	Y/N
2. Is the nearest latrine on higher ground than the well?	Y/N
3. Is there any other source of pollution (e.g. animal excreta, rubbish) within 10 m of the well?	Y/N
4. Is the drainage poor, causing stagnant water within 2 m of the well?	Y/N
5. Is there a faulty drainage channel? Is it broken, permitting ponding?	Y/N
6. Is the wall (parapet) around the well inadequate, allowing surface water to enter the well?	Y/N
7. Is the concrete floor less than 1 m wide around the well?	Y/N
8. Are the walls of the well inadequately sealed at any point for 3 m below ground?	Y/N
9. Are there any cracks in the concrete floor around the well which could permit water to enter the well?	Y/N
10. Are the rope and bucket left in such a position that they may become contaminated?	Y/N
11. Does the installation require fencing?	Y/N
Total score of risks .... /11	

Contamination risk score: 9–11 = very high; 6–8 = high; 3–5 = intermediate; 0–2 = low

III Results and recommendations

The following important points of risk were noted: .... (list nos 1–11) and the authority advised on remedial action.

Signature of sanitarian ....

Figure 1: Lloyd and Helmer's [5] sanitary survey form for open dug wells.

will then be analysed together with the source water quality (measured with FC counts /100ml of sample) to assess the current risk of the water supply.

The report form is a means to 1) identify potential faecal contamination origins of the water supply, 2) identify current risks attached to the water supply, 3) present the identified hazards in sketch form to the end user, and to keep a clear record of the hazards identified, and, 4) educating the stakeholders as to the impact of unsanitary conditions on the source water quality [5–7]. The combined risk assessment of sanitary hazards and water quality monitoring serves as a tool to prioritise remedial actions to improve the source water quality in collections of wells by reducing the contamination levels [5, 7].

Surveillance studies carried out by Lloyd and Boonyakarnkul [8] in Thailand, and Lloyd and Suyati [6] in Indonesia, have demonstrated the effectiveness of combined hazard assessment of point source groundwater supplies based on sanitary risk score and FC grading in prioritizing activities for the protection of well supplies. The procedures set out in Lloyd and Helmer [5] and WHO [2], for hazard assessment is, hence, easily applicable and efficient for application in developing countries.

2 Study area

Exploiting groundwater using open dug wells and on-site sanitation are common practices in South Asia, including the Maldives islands. Therefore the well water quality in the Maldives islands is at risk of faecal contamination. This paper presents the findings from a well surveillance study carried out in seven islands of the Maldives with the objective of developing a Water Safety Plan for the well water. The study islands were; Vilufushi, Thimarafushi, Veymandoo, Burunee, Fenfushi, Thoddoo and Daravandhoo. The study islands were chosen by the Director of MWSA (Maldives Water and Sanitation Authority, based on the history of well water quality issues.

3 Project outline

The well surveillance study in the Maldives involved the systematic survey of sanitary hazards present at the well and the well head area and faecal coliform (FC) count assessment, together with assessment of few physico-chemical parameters of well water.

The well water samples for FC counts were processed *in situ* and enumerated using a DelAgua field test kit. The observable sanitary hazards of open dug wells were surveyed using sanitary survey forms. For this purpose the published [2] sanitary survey forms were modified by the key author according to the context of the Maldives islands. The sanitary survey questions used in the Maldives islands were:

Q1: Is there a latrine present within 52.5m of the well?

Q2: Is there any other source of pollution (e.g. animal excreta, rubbish) within 52.5 m of the well?

Q3: Is the drainage poor, causing stagnant water within 2m of the well?

Q4: Is there a faulty drainage channel? Is it broken, permitting ponding?

Q5: Is the wall (parapet) around the well inadequate, allowing surface water to enter the well?
Q6: Is the concrete floor less than 1m wide around the well?
Q7: Are the walls of the well inadequately sealed at any point for 3m below ground?
Q8: Are there any cracks in the concrete floor around the well which could permit water to enter the well?
Q9: Is the groundwater abstraction means ('Dhani') left in such as position that it may become contaminated?

4 Results and discussion

The percentage occurrence of FC grades and sanitary hazards of open dug wells in the Maldives study islands are summarised in Tables 1 and 2. According to Table 1 FC grade D (100-1000 cfu/100ml) was the most frequently observed faecal contamination status of the well water. Table 2 demonstrates the very high frequency of occurrence of Qs 1 and 2, and emphasise the importance of local sources of latrine effluents. Based on the combined risk analysis (Tables 3 and 4), a majority (51%) of the wells in the study islands are at very high risk of faecal contamination and require urgent remedial action. Undertaking remedial actions to remove all the observed sanitary hazards in the Maldives study islands will require substantial capital investment, which is not always affordable within a short period of time by developing countries such as the Maldives islands. Therefore the remedial actions at individual sites will have to be prioritised based on the relative significance of the observed hazard points towards the faecal contamination of well water. At present there is no definite formula or methodology available to assess the relative significance of the observable sanitary hazards attached to open dug wells. Therefore regression analysis was carried out as a first step between the FC grade and the sanitary hazard based on the percentage occurrence of both parameters observed in each study island. The regression analysis results are summarised in Table 5.

According to Table 5, sanitary hazards ID2 (other source of pollution), ID3 (poor drainage causing stagnant water within 2m of the well) and ID5 (inadequate parapet wall allowing surface water to enter into the well) are not contributing towards any of the FC grades observed in the Maldives islands. Among the observed sanitary hazards, sanitary hazard ID **8** (*cracks in the plinth allowing water to enter the well*) showed relatively greater contribution (coefficient value of 0.0251) towards the worst FC grade E (>1000 CFU/100ml). This is followed in descending order by: Hazard ID **1** (*latrine located within 52.5m of the well*) coefficient value 0.170; Hazard ID 7 *(well walls inadequately sealed at any point for 3m below ground*) coefficient value 0.0159; Hazard ID 4 (*faulty drainage channel permitting ponding*) coefficient value 0.0065.

Overall, sanitary hazard ID 8 was the leading cause for FC grades D and E. However, no definite conclusion can be made on the relative significance of the sanitary hazards on the faecal contamination because, all of the observed hazards

Table 1: Percentage of occurrences of the observed faecal coliform grades in the Maldives study islands.

Study area	Grade A (0 cfu/100ml)	Grade B (1-10 cfu/100ml)	Grade C (11-100 cfu/100ml)	Grade D (101-1000 cfu/100ml)	Grade E (>1000 cfu/100ml)	No. of samples
Vilufushi	0.0	0.0	0.2	0.6	0.2	5
Thimarafushi	0.1	0.0	0.2	0.5	0.2	22
Veymandoo	0.0	0.0	0.3	0.4	0.2	21
Burunee	0.1	0.1	0.2	0.5	0.1	16
Fenfushi	0.3	0.3	0.1	0.0	0.3	16
Thoddoo	0.4	0.0	0.1	0.1	0.4	16
Daravandhoo	0.3	0.5	0.3	0.0	0.0	8
Overall	***0.2***	***0.1***	***0.2***	***0.3***	***0.2***	***104***

Table 2: Percentage of occurrence of sanitary hazards of open dug wells in the Maldives islands.

Study area	Hazard question ID									Number of sites
	1	2	3	4	5	6	7	8	9	
Vilufushi	0.0	80.0	100.0	100.0	60.0	100.0	80.0	100.0	20.0	5
Thimarafushi	100.0	100.0	17.4	4.3	0.0	13.0	17.4	52.2	82.6	22
Veymandoo	100.0	100.0	57.1	47.6	0.0	85.7	0.0	95.2	47.6	21
Burunee	100.0	100.0	18.8	6.3	0.0	75.0	18.8	87.5	68.8	116
Fenfushi	100.0	100.0	62.5	56.3	6.3	56.3	12.5	68.8	56.3	16
Thoddoo	100.0	100.0	87.5	81.3	12.5	93.8	12.5	93.8	68.8	16
Daravandhoo	100.0	100.0	60.0	70.0	0.0	60.0	0.0	70.0	60.0	8
Overall	95.2	99.0	51.0	42.3	5.8	63.5	14.4	78.8	62.5	104

Table 3: Combined risk analysis of sanitary inspection and faecal coliform contamination.

Faecal grade	+	Sanitary Risk grade	Action priority
A/B	+	Low risk (0<SHS<2)	Low priority
C	+	Intermediate to high risk (3<SHS<8)	Higher priority; as soon as resources permit
D/E	+	Very high risk (SHS≥9)	Highest priority; most urgent action

Source: Adopted from Lloyd and Helmer [5].

Table 4: Grouping of open dug wells according to the associated risk of faecal contamination, arranged by study areas.

Study area	No. of sample	Low risk: Low action priority	Intermediate to high risk: Higher action priority	Very high risk: Urgent action
Vilufushi	5	0	1	4
Thimarafushi	22	0	7	15
Veymandoo	21	0	8	13
Burunee	16	0	6	10
Fenfushi	16	1	11	4
Thoddoo	16	1	8	7
Daravandhoo	8	1	7	0
Total	104	3	48	53
% occurrence		***2.9***	***46.2***	***51.0***

Table 5: Summary of regression coefficients of sanitary hazards attached to each faecal contamination grade observed in the Maldives study islands.

	FC grade A	FC grade B	FC grade C	FC grade D	FC grade E
Regression Statistics					
R Square	1	1	1	1	1
Standard Error	0	0	0	0	0
Coefficients					
Intercept	-0.9297	3.2279	1.1018	0.1345	-2.5346
Hazard question ID					
1	0.0107	-0.0072	-0.0090	-0.0115	**0.0170**
2	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0050	-0.0052	-0.0018	-0.0046	0.0065
5	0.0000	0.0000	0.0000	0.0000	0.0000
6	0.0015	0.0266	0.0001	-0.0124	-0.0159
7	0.0097	-0.0089	-0.0106	-0.0062	0.0159
8	-0.0052	-0.0462	0.0008	0.0255	**0.0251**
9	0.0008	-0.0021	0.0016	0.0053	-0.0055

with regression coefficient values above zero exhibited different rank of relative contribution attributable to individual FC grading. For example sanitary hazard ID1 was attributable to FC grade E as well as FC grade A. This is because the on-site sanitation systems in the Maldives islands are *all located within the safe separation distance from open dug wells*. Hence, the impact of the on-site sanitation system on the microbial well water quality will always be present irrespective of the presence of other observable sanitary hazards.

Two other approaches [8, 9] were also tried to assess the relative significance of the sanitary hazards towards the microbial well water quality. Lloyd and Boonyakarnkul [8] used Sanitary hazard Index as a tool to weigh the relative significance of the sanitary hazards of tube wells. “The SHI is an association rating between the intensity of faecal coliform contamination and each sanitary hazard point revealed by inspection of a selected number of facilities” [8]. The SHI methodology was shown effective in prioritising the remedial action, applied to tube wells, to reduce the faecal contamination level [8]. The application of the SHI tool was shown to be effective for a collection of groundwater point sources which are *constructed to a common design and tapping groundwater from common aquifer type*. Open dug wells in the Maldives islands were constructed according to the owner or mason’s design. Nevertheless the well construction methods and the structures were very much similar within the Maldives islands. Also the groundwater aquifers in the Maldives islands are of the same formation (lens formation of the freshwater floating on top of the saline water).

Therefore the SHI values for the sanitary hazards of the open dug wells in the Maldives islands were assessed based on the following steps [10].

a) Extract from database all records of one facility type
b) Convert all records for faecal coliform counts to logarithmic faecal coliform counts. To prevent problems with log 0, add 0.1 to every faecal coliform count prior to conversion
c) Calculate geometric mean of faecal coiform counts = x
d) Extract from records, for each sanitary hazard question, all records with a ‘Yes’ and associated log faecal coliform counts
e) Calculate geometric mean of faecal coliform counts for each question = n
f) SHI for each question = n-x
g) Rank order SHI

The summary of the SHI values of the sanitary hazards observed in the Maldives islands are presented in Table 6. In Table 6, the sanitary hazards are arranged in a rank order with descending SHI values. Sanitary hazard ID5 (absence of parapet wall letting surface water enter into the well) was the least observed (Table 2, 5.8%) sanitary hazard in the Maldives islands. However, when the parapet wall was absent (Vilufushi and Thoddoo islands) at some instances, it was relatively the most significant hazard causing faecal contamination of well water (Table 6).

Among those sanitary hazards with positive SHI value, hazard ID9 (groundwater abstraction mean, ‘Dhani’, left in unsanitary condition) was commonly observed in all study islands (Table 6). Therefore this is also a significant hazard of the open dug wells in the Maldives islands. The sanitary hazard ‘poor drainage causing stagnant water within 2m of the well’ is another significant hazard (ID3) (other than hazards ID 5 and 9) widely observed in the Maldives islands with positive SHI, except in the Fenfushi island. Except for the above-mentioned three sanitary hazards (ID 5, 9 and 3) the relative significance (SHI) of all other hazards observed in the Maldives islands showed no regular pattern.

Cronin *et al*. [9] used the median observed Thermo-Tolerant Coliform (TTC) counts and the relative frequency of the sanitary hazards with which the sanitary hazards occur above and below the median TTC.

Cronin *et al*. [9] showed that the sanitary hazards with greatest positive percentage difference from the median TTC had closer correlation with faecal contamination levels. According to Cronin *et al*.’s [9] methodology sanitary hazard ID9 (groundwater abstraction mean, ‘Dhani’ left at unsanitary condition) was the relatively significant hazard observed with open dug wells in all the Maldives study islands causing the faecal contamination of well water. The relative significance of all the other sanitary hazards was not regular among the study islands.

The relative significance of the hazard ID1 (presence of latrines within the safe separation distance) was identified as null in all three combined risk analysis methodologies above (regression analysis, SHI and median TTC) even though the proximity to on-site sanitation system of a dug well can be an important cause for microbial contamination of well water. This could be a result of this hazard’s (ID1) abandoned occurrence in all the study areas. The same is applicable to Hazard ID2 (occurrence of other sources of pollution).

The coral sand and rock formation of the Maldives islands cause the aquifer to be very vulnerable to surface applied contamination. According to most of the bore logs from previous studies, the top 10m of the Maldives geology is comprised of medium and coarse grained coral sand and loose coral rocks [11]. In the absence of the biologically active soil layer, this most important first defence against the penetration of surface applied contaminants is absent in the Maldives islands. Adding to the vulnerable aquifer characteristics, the on-site sanitation system latrines are constructed partly within the aquifer causing direct faecal contamination of groundwater. The unlined construction of the latrine pits fails to contain the pollutants at the source.

In addition to these very vulnerable conditions of the groundwater, the proximity of the open dug wells to the on-site sanitation system is witnessed everywhere in the Maldives study islands due to their very small extent (Table 7).

Therefore differentiating the relative significance of the sanitary hazards in the faecal contamination of open dug wells is a difficult task. As a first step the impact from the on-site sanitation system on the microbial quality of well water needs to be eliminated in order to identify the impact of the other observable sanitary hazards of open dug wells in the Maldives islands.

Table 6: Summary of sanitary Hazard Index (SHI) values of the sanitary hazards of the open dug wells observed in the Maldives islands, arranged in descending order of the SHI values.

Rank	Vilufushi		Thimarafushi		Veymandoo		Burunee		Fenfushi		Thoddoo		Daravandhoo	
	Hazard ID	SHI	Hazard ID	SHI	Hazard ID	SHI	Hazard ID	SHI	Hazard ID	SHI	Hazard ID	SHI	Hazard ID	SHI
Rank 1	**5**	0.17	**7**	0.65	**9**	0.50	**7**	0.76	**9**	0.82	**5**	1.61	**6**	0.69
Rank 2	**9**	0.09	**3**	0.59	**4**	0.48	**9**	0.46	**1**	0.00	**4**	0.44	**3**	0.65
Rank 3	**3**	0.00	**4**	0.57	**3**	0.26	**3**	0.24	**2**	0.00	**9**	0.28	**4**	0.65
Rank 4	**4**	0.00	**9**	0.14	**8**	0.01	**1**	0.00	**4**	-0.02	**3**	0.21	**8**	0.65
Rank 5	**6**	0.00	**1**	0.00	**1**	0.00	**2**	0.00	**3**	-0.05	**6**	0.18	**9**	0.12
Rank 6	**8**	0.00	**2**	0.00	**2**	0.00	**6**	-0.05	**8**	-0.19	**8**	0.18	**1**	0.00
Rank 7	**2**	-0.02	**8**	-0.16	**6**	-0.09	**8**	-0.07	**6**	-0.72	**1**	0.00	**2**	0.00
Rank 8	**7**	-0.02	**6**	-2.07	**5**		**4**	-0.33	**5**	-2.09	**2**	0.00	**5**	
Rank 9	**1**	-2.61	**5**		**7**		**5**		**7**	-2.09	**7**	-0.99	**7**	

Table 7: Summary of the percentage frequency of occurrence of hazard points with median faecal coliform grade observed in the Maldives islands.

Vilufushi		Thimarafushi		Veymandoo		Burunee		Fenfushi		Thoddoo		Daravandhoo	
ID*	Relative frequency	ID*	Relative frequency	ID*	Relative frequency	ID*	Relative frequency	ID*	Relative frequency	ID*	Relative frequency	ID*	Relative frequency
9	25.0	**9**	15.2	**4**	36.5	**9**	56.7	**9**	23.6	**9**	30.0	**3**	83.3
1	0.0	**4**	6.7	**9**	36.5	**3**	3.3	**1**	0.0	**4**	23.3	**4**	83.3
3	0.0	**1**	0.0	**3**	11.5	**7**	3.3	**2**	0.0	**5**	20.0	**8**	83.3
4	0.0	**2**	0.0	**1**	0.0	**1**	0.0	**5**	-20.0	**6**	16.7	**6**	66.7
6	0.0	**5**	0.0	**2**	0.0	**2**	0.0	**3**	-25.5	**8**	16.7	**9**	16.7
8	0.0	**3**	-15.2	**5**	0.0	**5**	0.0	**4**	-34.5	**3**	6.7	**1**	0.0
2	-25.0	**7**	-15.2	**7**	0.0	**6**	-13.3	**7**	-40.0	**1**	0.0	**2**	0.0
7	-25.0	**6**	-21.9	**6**	-2.9	**4**	-16.7	**8**	-45.5	**2**	0.0	**5**	0.0
	-50.0	**8**	-24.8	**8**	-7.7	**8**	-20.0	**6**	-63.6	**7**	-6.7	**7**	0.0

*Hazard ID.

Table 8: The extent of the Maldives study islands.

study islands	Vilufushi	Thimarafushi	Veymandoo	Burunee	Fenfushi	Thoddoo	Daravandhoo
Area (ha)	61	14.5	40.8	30.5	24.2	173.8	56.1

5 Conclusions

Therefore the expected benefit of using combined sanitary survey and faecal contamination level assessment to prioritize specific remedial actions to improve the microbial quality of well water was not realized in this study, in contrast to earlier published studies. The principal reasons for this methodological failure are:

1. *the geological setting of the Maldives is extremely vulnerable overall, particularly since there is effectively no soil layer*
2. *in the absence of a soil layer septic tanks are constructed partly within the shallow aquifer resulting in direct faecal contamination of the aquifer by tank effluents*
3. *basic rules of construction of septic tanks e.g. water tight tank linings and tile field construction for effluent treatment, are ignored, compounding the problem of direct faecal contamination*
4. *the close proximity of septic tank effluents to dug wells occurs almost everywhere, and overwhelms the contribution of all other potential hazards.*

6 Recommendation

To improve the microbial quality of well water in the Maldives islands, effectively containing the pollutants at the source with proper construction of water seal on-site sanitation systems and maintenance is foremost important step which is recommended by this paper.

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